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MEMORANDUM REPORT ARBRL-MR-03036

SHIELDING FROM BLAST EFFECTS - 1/8TH SCALE MODEL CITY COMPLEX

George A. Coulter

July 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Blast Effects	Overpressure
City Complex	Shielding
Loading	Wall Loading

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

1/8th scale model houses were exposed to an average 26 kPa (3.77 psi) blast loading from 490 kg (1080 lb) pentolite charges. Various configurations of shielding were used to determine the change in blast pressure loading on the walls, roof, and at locations inside the model. Comparisons of the recorded pressure-time histories are shown for unshielded, in-line shields, and for the test model within a complex of similar house models.

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I. INTRODUCTION

The Defense Nuclear Agency (DNA) sponsored the present work at the Ballistic Research Laboratory (BRL) as a part of its collateral damage program. The general objective of the collateral damage program is to ultimately be able to furnish guidance to the field commander when there is a need to fire a tactical nuclear weapon nearby to a friendly town or city. The field commander should be able to complete his mission within the prescribed acceptable level of damage to the friendly area. The pressure-time loading on structures at specified yield-distances is needed to generate the needed probable damage functions for the field commander.

The particular concern addressed by this set of experiments[1] was to determine the amount of shielding, if any, that a row of houses in a town or city complex might afford the next row across the street from it. Accordingly, a 1/8th scale model city complex[2] was designed and exposed to the 1978-79 height-of-burst (HOB) tests at the Defense Research Establishment Suffield, Alberta, Canada (DRES). The model complex was included as one of several experiments carried out during this test series code-named Mighty Mach I and II. The two sets of firings used nominal 490 kg (1000 lb.) pentolite charges to produce the blast waves that were used to load the model complexes. Section II describes the experiments.

II. TEST PROCEDURE

Details of the house model used, shielding configurations, and the instrumentation are described in this section.

A. 1/8th Scale Model House

A simplified 1/8th scale model of a "standard" two-story house was designed, constructed, and instrumented with pressure transducers at the various numbered locations shown on the model (Figure 1). The model (and the models making up the complex) was constructed of heavy plywood (2.54 cm) and mounted to a concrete pad with heavy steel angles (5.08 x 5.08 x 0.63 cm thick).

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[1] *A complementary set of experiments was performed in the BRL 2.44 m shock tube for an unshielded model house. G. Coulter, "Blast Wave Loading of a 1/15th Scale House",* Memorandum Report ARBRL-MR-03031, dated July 1980.

[2] *Earlier work with very small scale shock tube models indicated some protection was given by shielding. A.B. Willoughby, "Blast Shielding in Complexes", Broadview Res Corp, AFSWC TR 57-29, August 1958.*

The house model was used in the test configurations in two designs. The first design had no openings. This type model was intended to simulate the case where doors are closed and windows are shuttered. The second case had door and window openings added. This was intended to simulate a case where all doors and windows would be immediately blown to full open positions by the blast wave. Figures 1 - 4 show details of the model.

The various shielding configurations for the model and the complexes are described in the next part of the section.

B. Shielding Configurations

Three test sites were chosen, each one on a 57.91 m (190 ft.) radius measured along the ground from a ground zero point (GZ) directly under the suspended charge. The sites were chosen to expose the model houses to a nominal 26 kPa (3.77 psi) peak blast overpressure at the ground station locations.

Site A, Figure 5, was constructed so as to cause an in-line shielding effect upon the house model. The shields were then removed to expose the model alone. This particular model house was left on Site A as a control model for all the remaining shots of the test. A twin house model had been earlier constructed to be used in the shots upon the complexes.

Site B was positioned so as to expose the complex there to a 0° angle of incidence to the blast wave. Figure 6 illustrates this site. A small portion of a city suburb was modeled, including two rows of back-to-back houses and a street. Two of the shielding houses were physically joined to make a row house out of them.

Site C was identical to Site B except it was positioned so that the blast wave angle of incidence with the front walls was 45°. Figure 7 shows the test layout for Site C. The center bottom of the front wall of the instrumented model was placed at the same radial distance from GZ as the free-field ground station 190.0C. Figure 8 shows photographs of model complexes as installed on the sites.

C. Instrumentation

Pressure transducers were located at the free-field ground station and at the several locations on the model house. There were stations located on the left half (as seen from GZ) of the two instrumented models: the front wall, front roof, rear roof, rear wall, and left side wall. On the open models, a station was added in both the attic floors and the ground floors of the models.

MODEL HOUSE

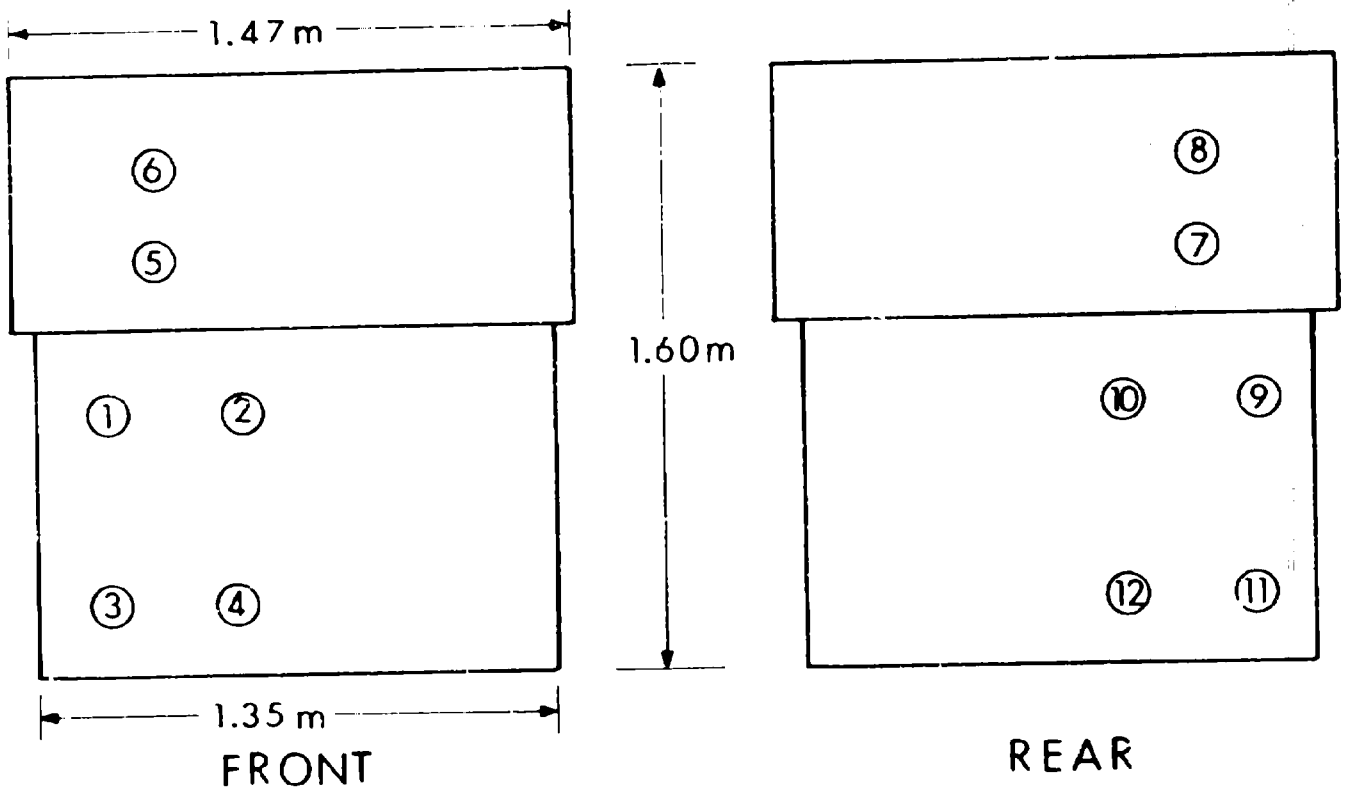


Figure 1. Sketch of 1/8th scale model house - no openings.

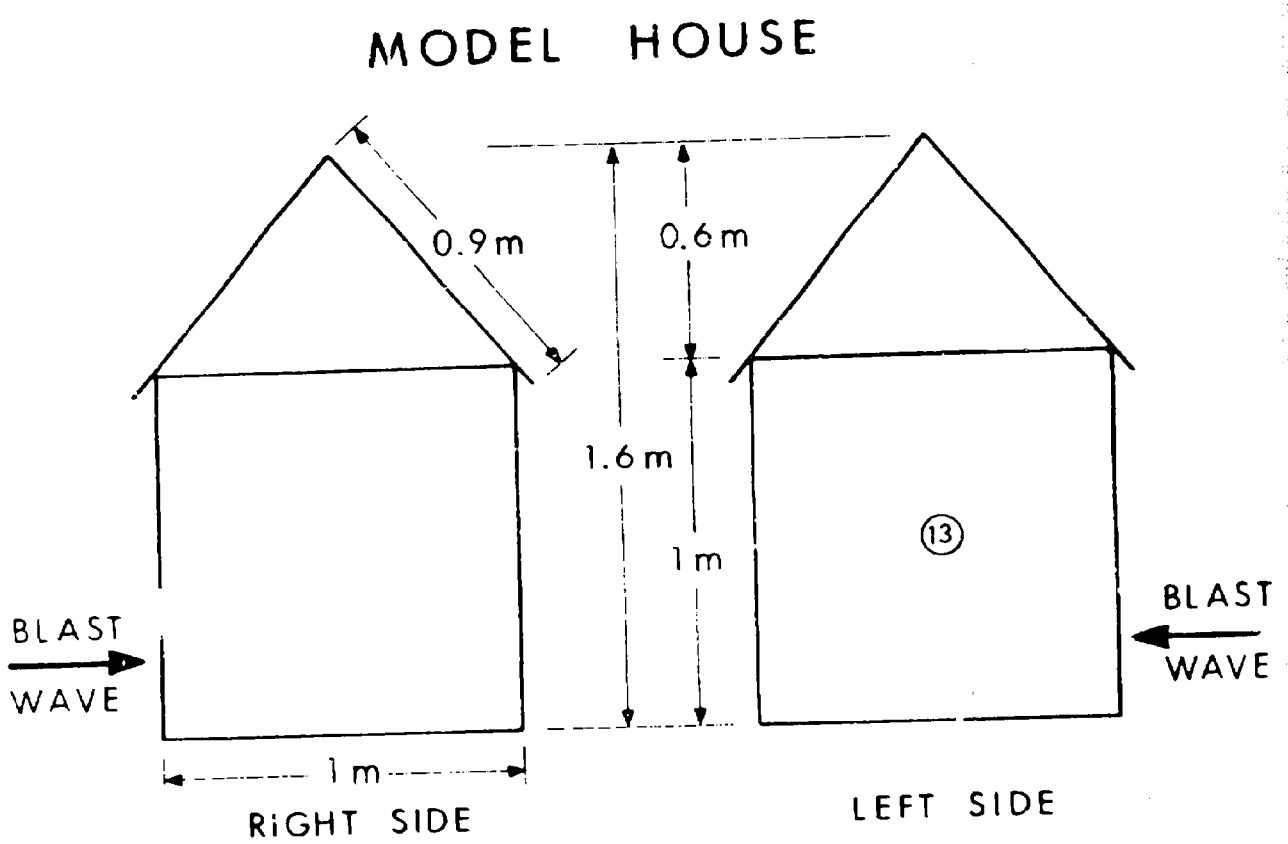


Figure 1. (Cont) Sketch of 1/8th scale model house - no openings.

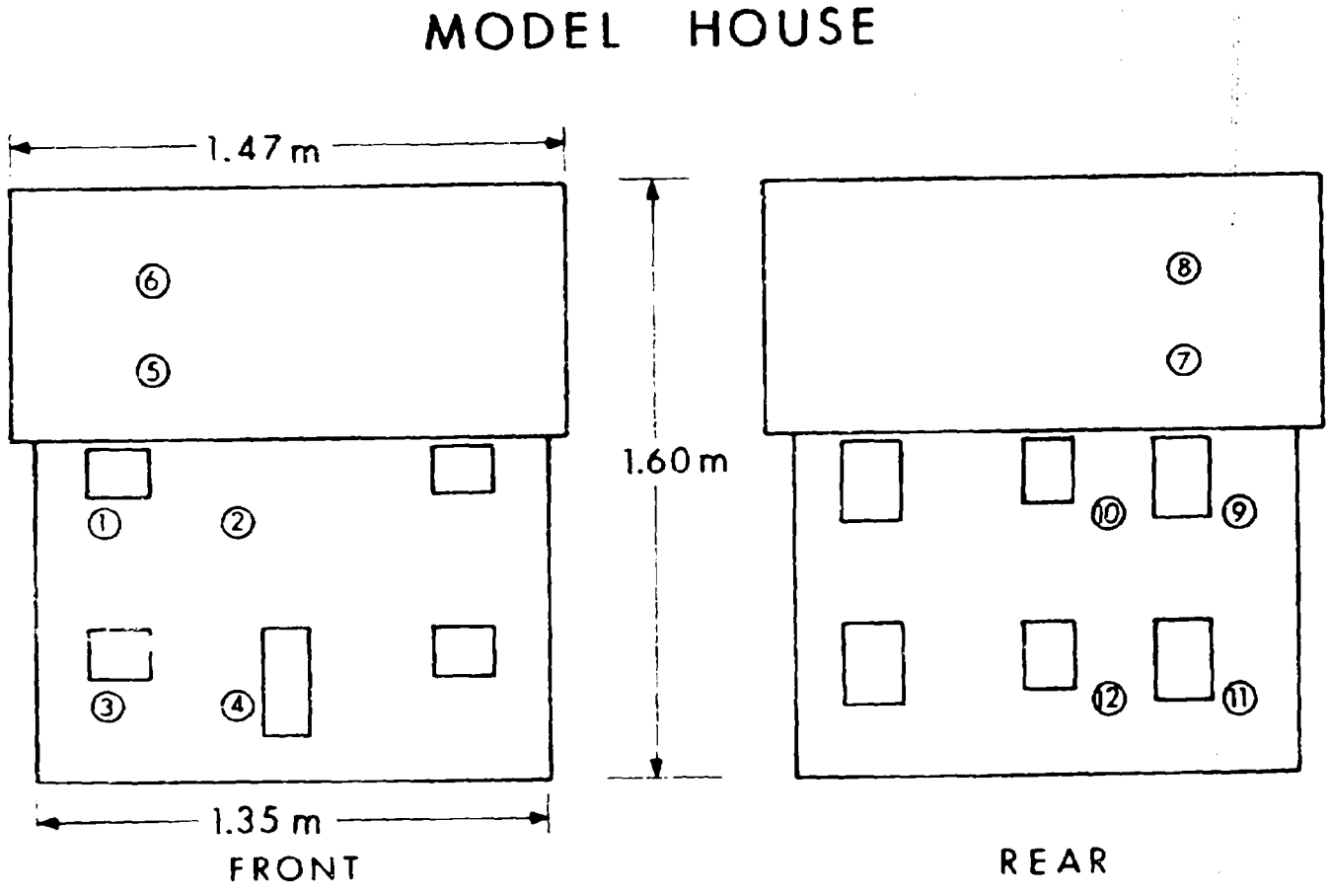


Figure 2. Sketch of 1/8th scale model house - with openings.

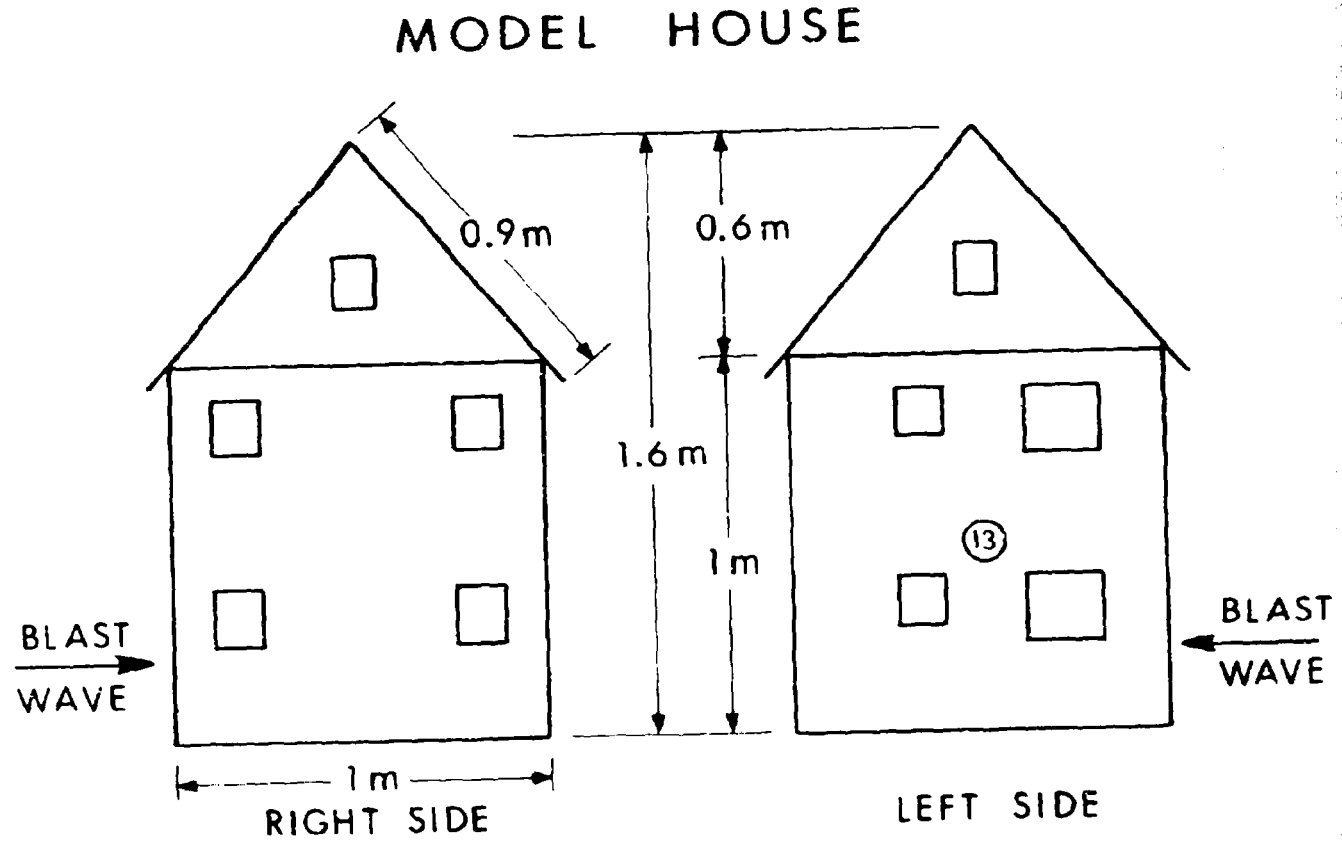
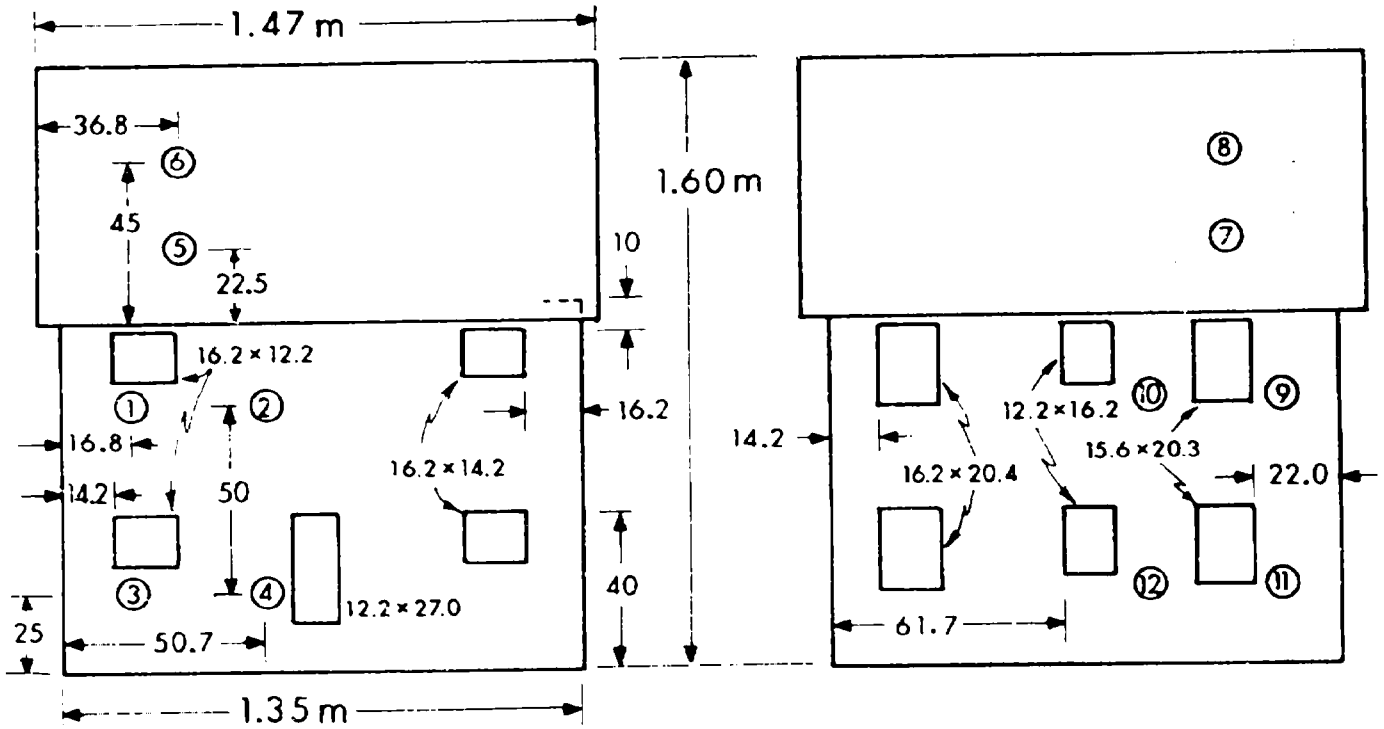


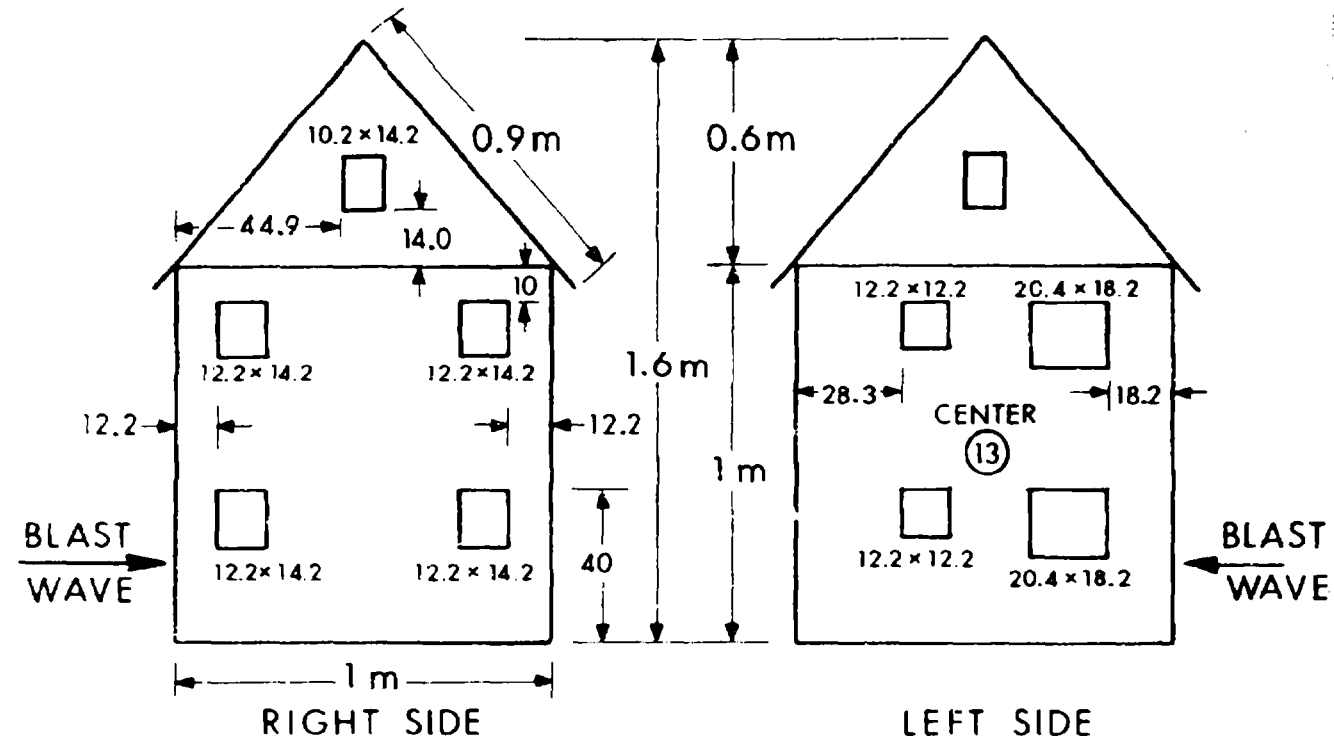
Figure 2. (Cont) Sketch of 1/8th scale model house - with openings.

MODEL HOUSE



NOTE: ALL DIMENSIONS ARE IN CENTIMETRES
UNLESS OTHERWISE SPECIFIED

Figure 5. Location of transducers on model.



NOTES: 1 ST. 51 WAS INSIDE ATTIC ON CENTER OF FLOOR
2 ST. 71 WAS INSIDE ON CENTER OF GROUND FLOOR
3 ALL DIMENSIONS ARE IN CENTIMETRES UNLESS OTHERWISE SPECIFIED

Figure 5. (Cont) Location of transducers on model.

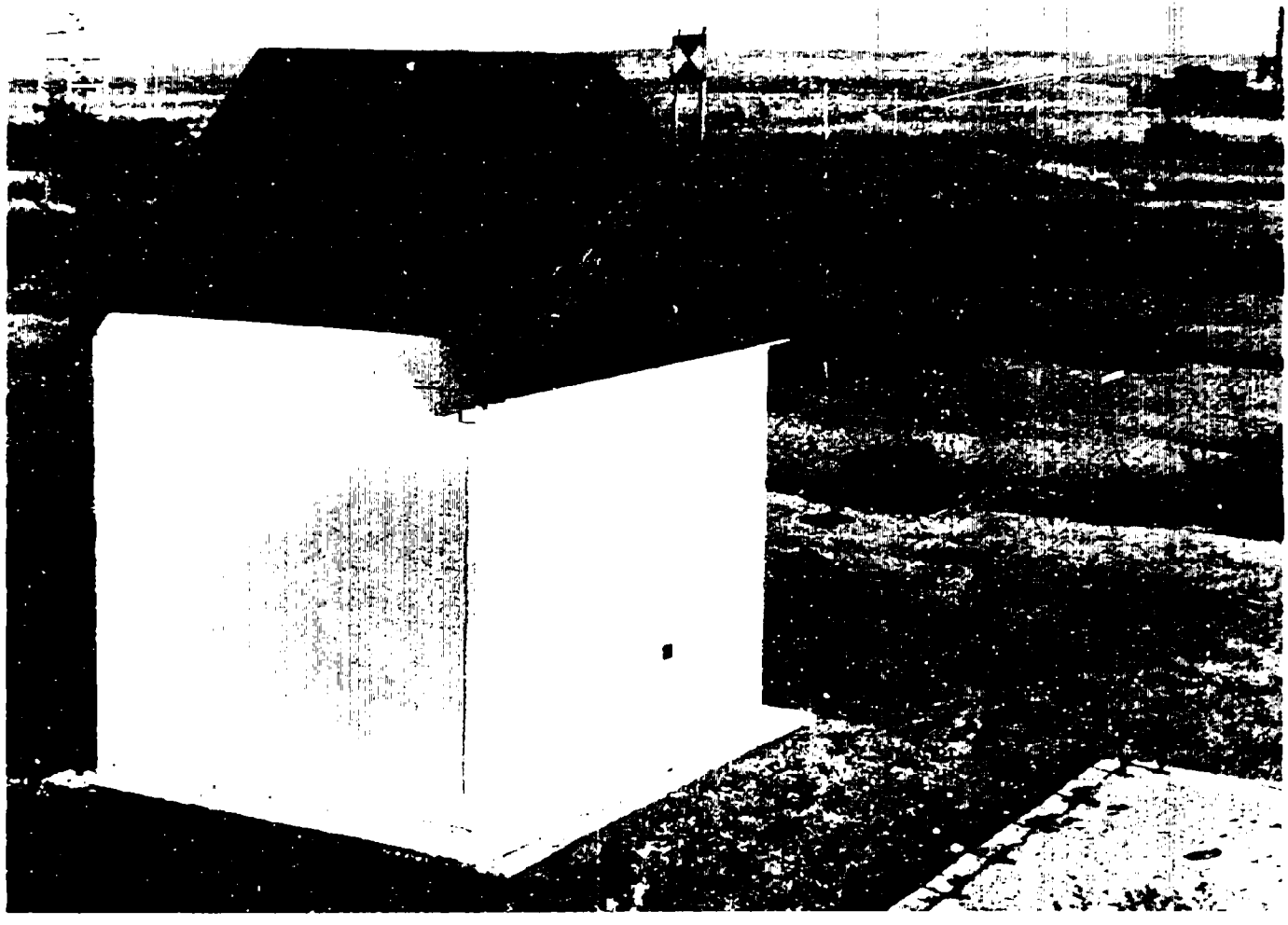


Figure 4. Photographs of model house.

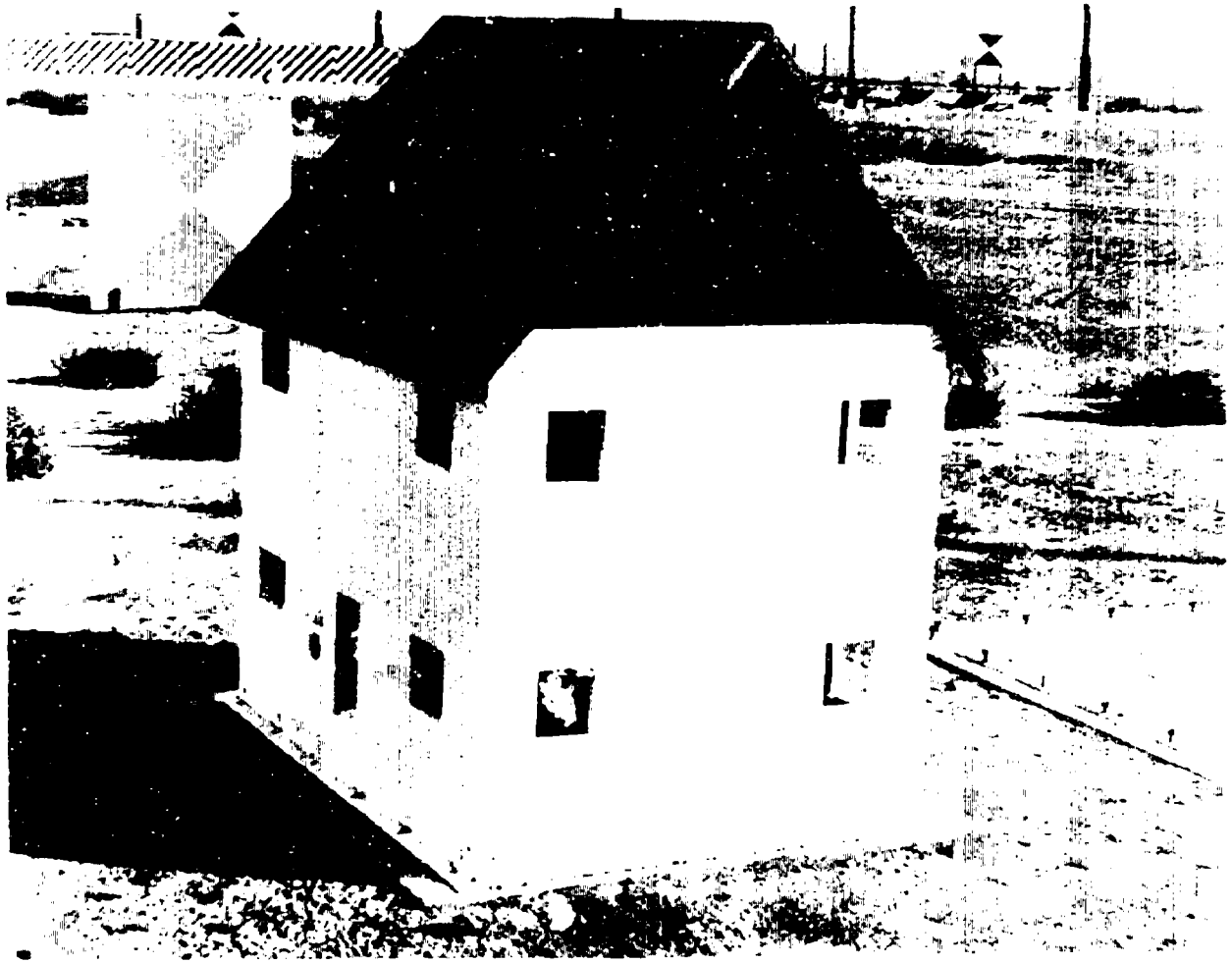
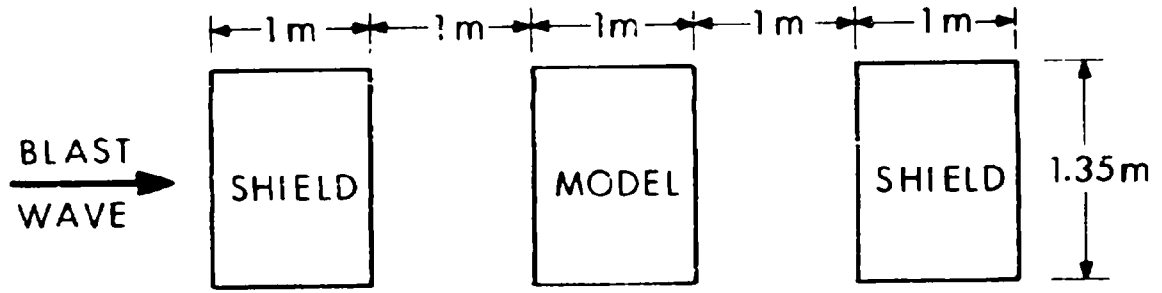


Figure 4. (Cont) Photographs of model house.

SITE A

IN-LINE SHIELDING; MIGHTY MACH I, SHOT 2



GROUND STATION
● No. 190.0

NOTES:
1 MODEL LEFT ON SITE A WITHOUT SHIELDS – FOR COMPARISON WITH MIGHTY MACH II, SHOTS 3-7
2 STATIONS 4, 6, & 12 ONLY, ACTIVE FOR SHOTS 4-7

Figure 5. In-line shields at Site A.

SITE B

SHIELDING COMPLEX; MIGHTY MACH II, SHOTS 4 & 7

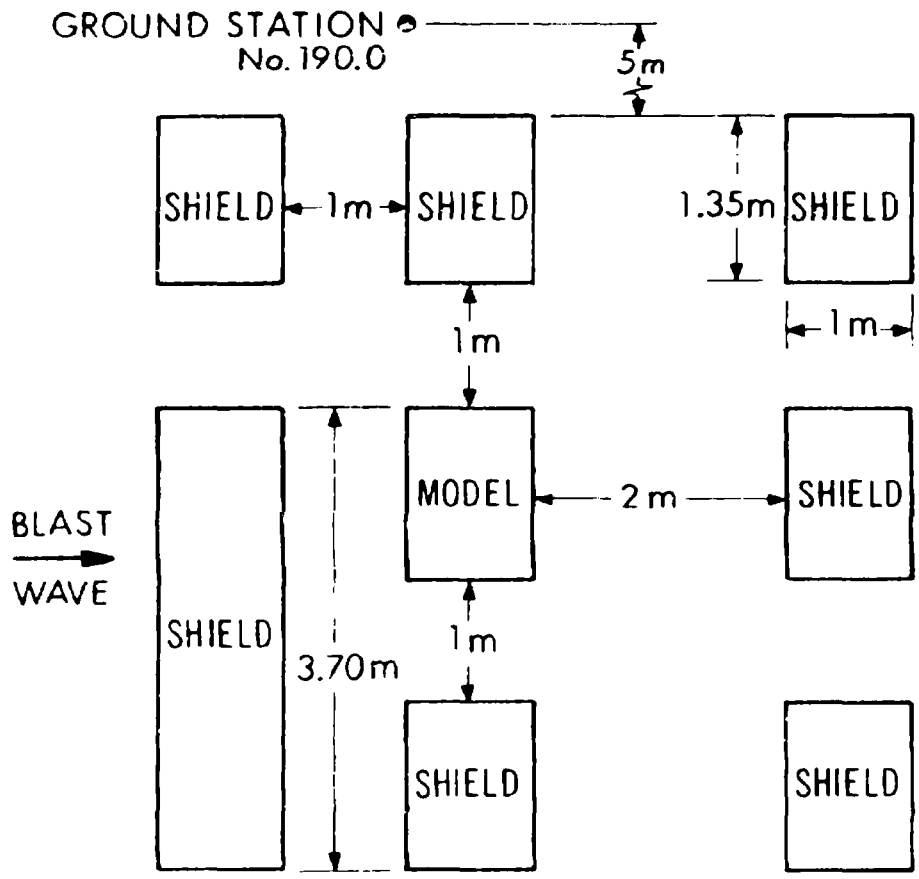


Figure 6. Shielding complex on Site B - 0° angle of incidence to blast wave.

SITE C

SHIELDING COMPLEX; MIGHTY MACH II, SHOTS 5 & 6

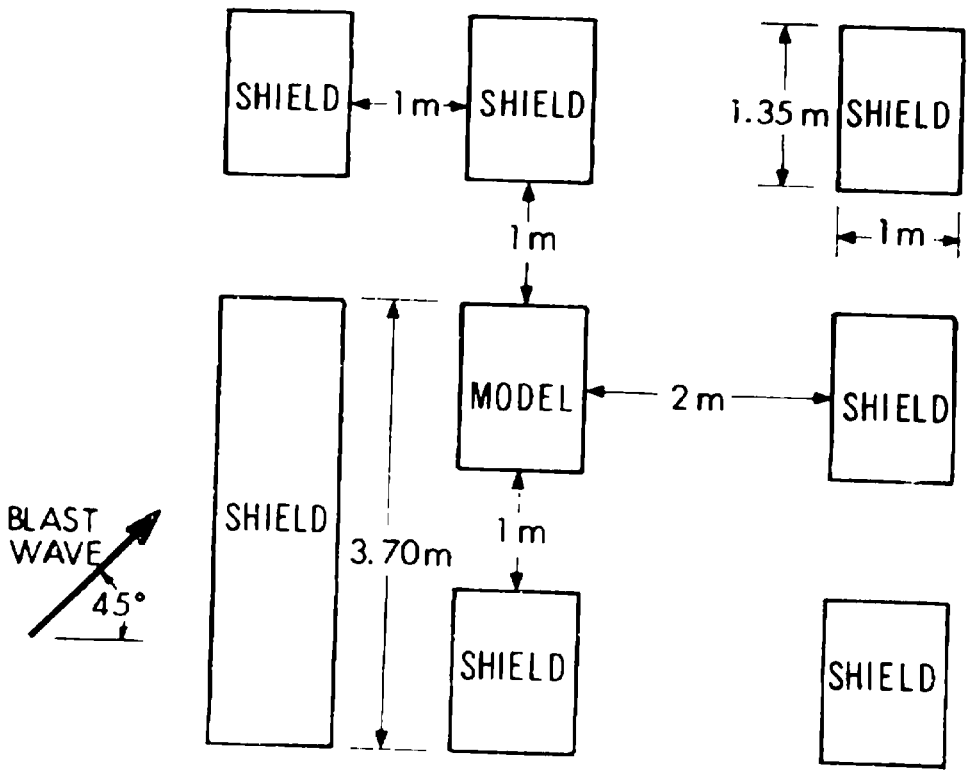


Figure 7. Shielding complex on Site C - 45° angle of incidence to blast wave.

Figure 8. Photographs of the model complexes.

Figure 8. (Cont) Photographs of the model complexes.

The schematic of Figure 9 shows the complete data acquisition system. The pressure transducers used for all stations were of the strain bridge type, Tyco-Bytrex Model HFG. Signal conditioners and amplifiers allowed the voltage output from the blast loaded transducers to be recorded by the 40 kHz Sangamo 4784 FM tape recorder. The records from the 32 track machine were dubbed on-site and reduced to digital from analog in the laboratory data reduction facility. The remainder of the system allowed report-ready data to be prepared from the digital processing.

III. RESULTS

The blast loading measurements will be discussed according to the model configurations tested. Table I lists the test series in order of shots fired.

A. Unshielded Model

Shot 3 was fired when the fully instrumented 1/8th model house was located on Site A. For this shot no openings were in the model. Transducer stations were located on the front wall, front roof, rear roof, rear wall, and on the left side wall. The free-field pressure was also monitored on this and on each succeeding shot at the 190.0A or 190.0B (190.C same as 190.0B) ground station.

Pressure-time histories from each of the instrumented surfaces are shown as examples in Figure 10. The free-field blast wave (Station 190.0A) is exponentially decaying from a peak overpressure of about 28 kPa to zero pressure in a positive duration of about 30 ms.

Peak pressures on the front wall and roof are reflected values for the blast wave (58-63 kPa) after interacting with the surfaces. They are always characterized by steepened peaks. Station 190.2A shows a secondary peak, near the initial peak, caused by an "extra" reflection from the overhanging roof.

Station 190.8A on the rear roof shows a slightly rounding of the wave's first portion. The maximum overpressure is at this time about 21 kPa, less than free-field. The rear wall station, 190.12A, shows even more rounding of the blast wave profile.

Station 190.13A on the left side wall shows a profile something like the free-field with a vortex probably causing the sharp decay at about 5 ms.

Table II lists some pertinent parameters for Shot 3 with the unshielded model.

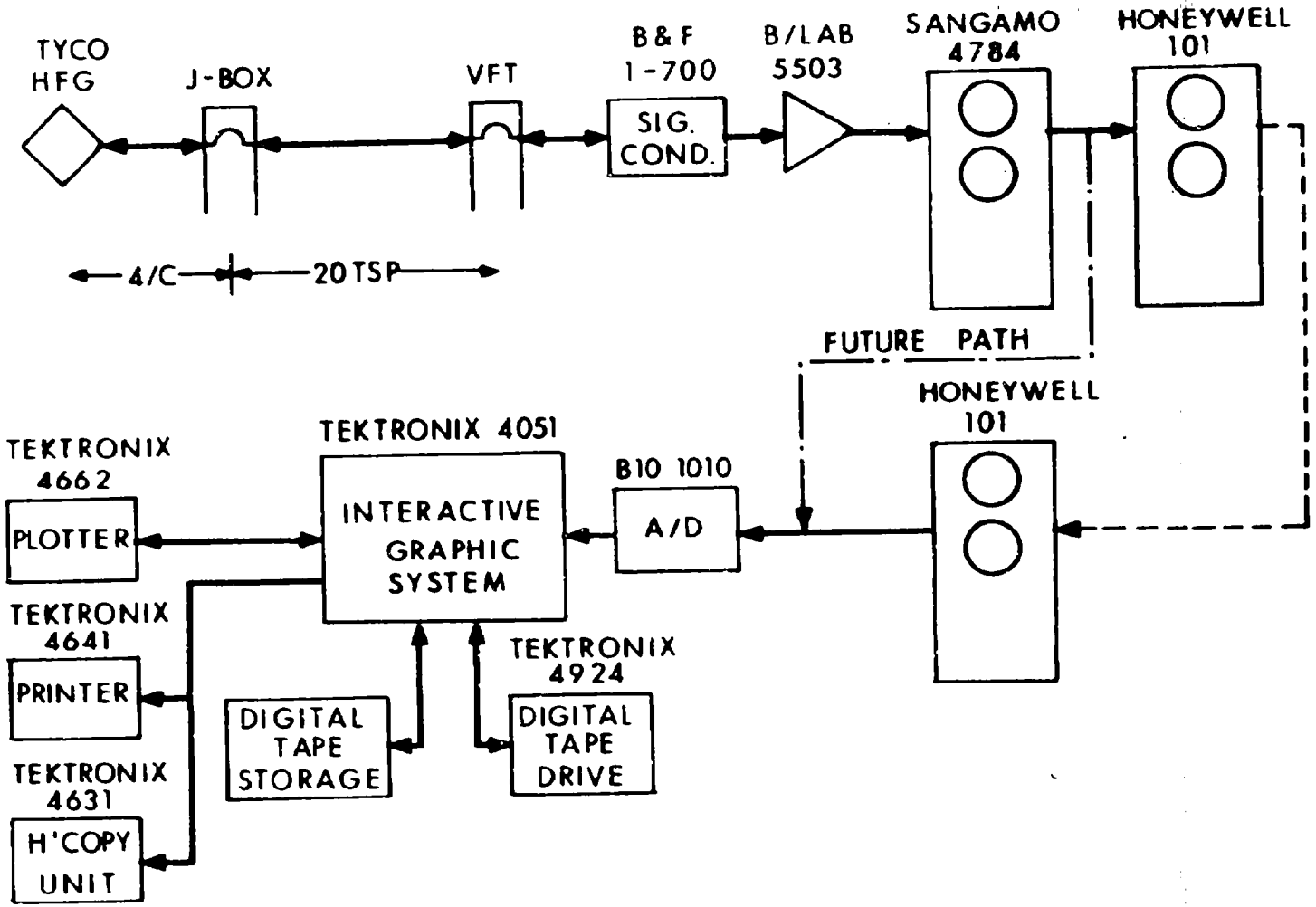


Figure 9. Schematic of data acquisition system.

Table I. Record of Shots

Shot No.	Test Series	Date	Pentolite Charge wt, kg	HOB, m	Ambient Pressure, kPa	Ambient Temp, °C	Wind Speed, km/h	Model Configuration
2	Mighty Mach I	20 Sept 78	490.8	4.57	93.4	15.4	8.0	In-line shields
3	Mighty Mach II	08 Aug 79	490.8	4.56	93.0	26.0	9.0	Unshielded model
4	Mighty Mach II	17 Aug 79	490.8	4.55	93.3	30.8	6.4	0° Complex, Closed Model
5	Mighty Mach II	27 Aug 79	486.2	3.04	92.4	28.9	4.8	45° Complex, Closed Model
6	Mighty Mach II	05 Sept 79	493.1	3.05	93.4	24.3	4.0	45° Complex, Open Model
7	Mighty Mach II	12 Sept 79	484.4	3.05	94.1	17.8	9.2	0° Complex, Open Model

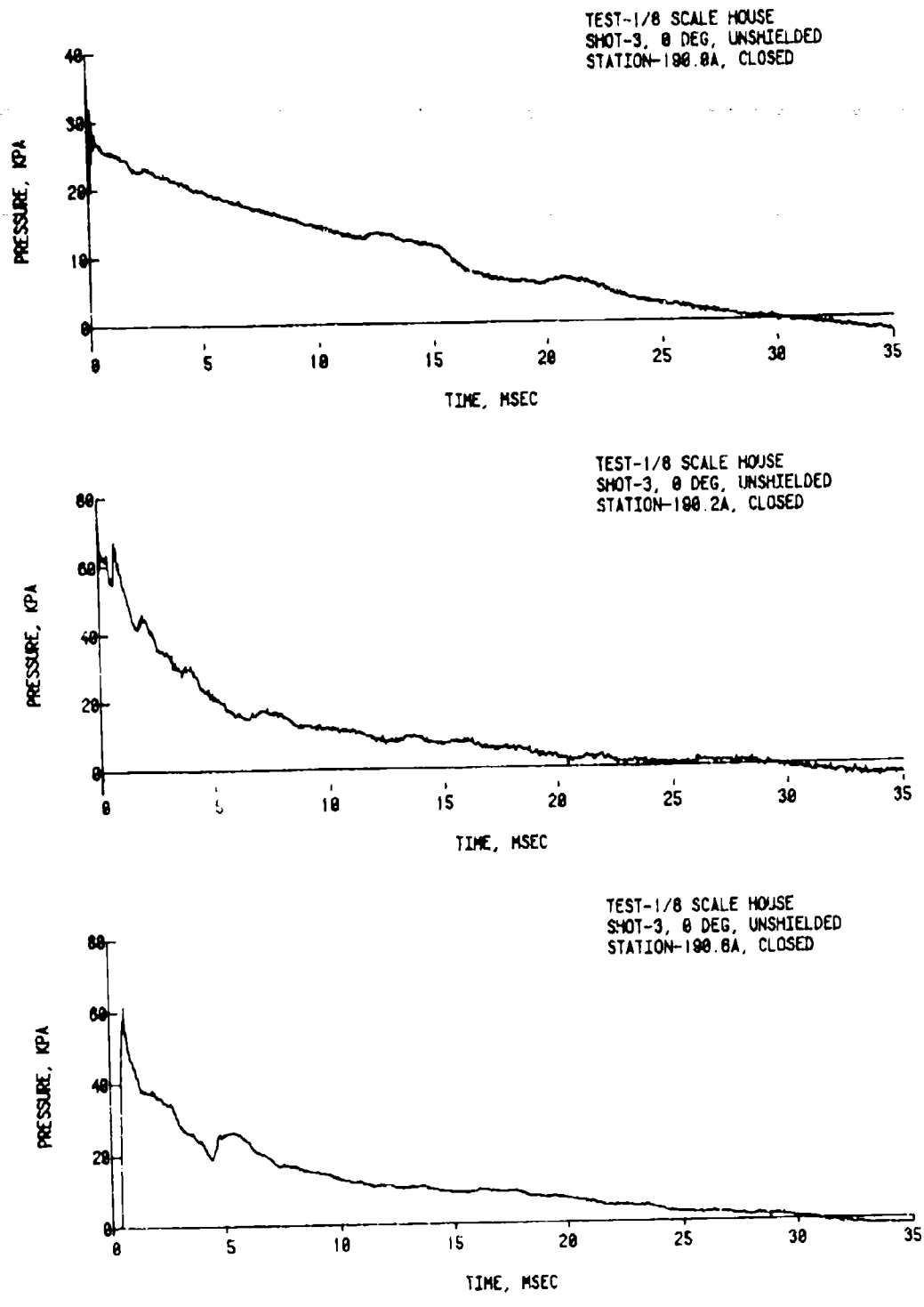
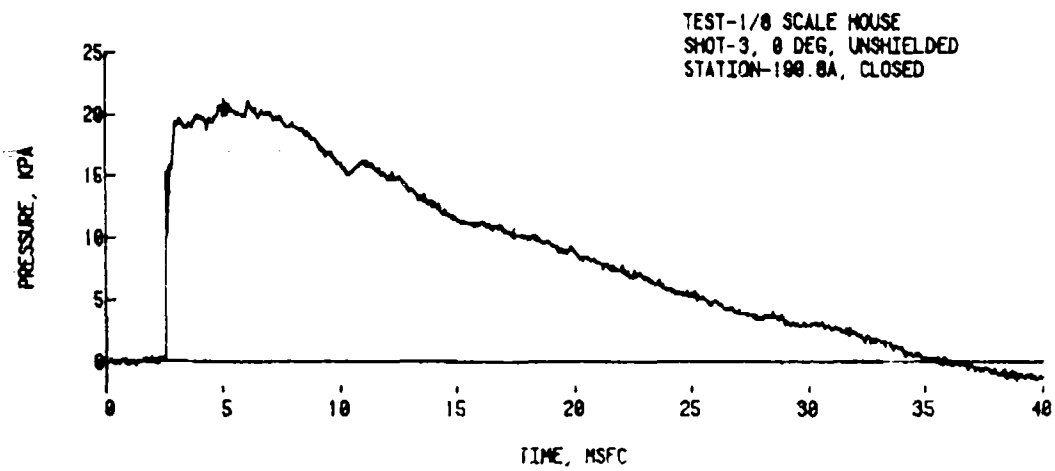
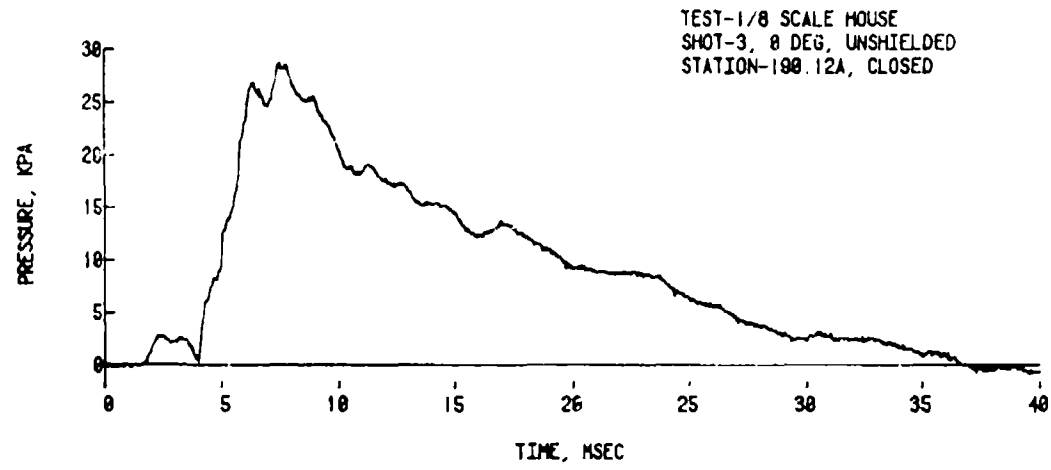


Figure 19. Pressure-time records from Shot 3, unshielded model.





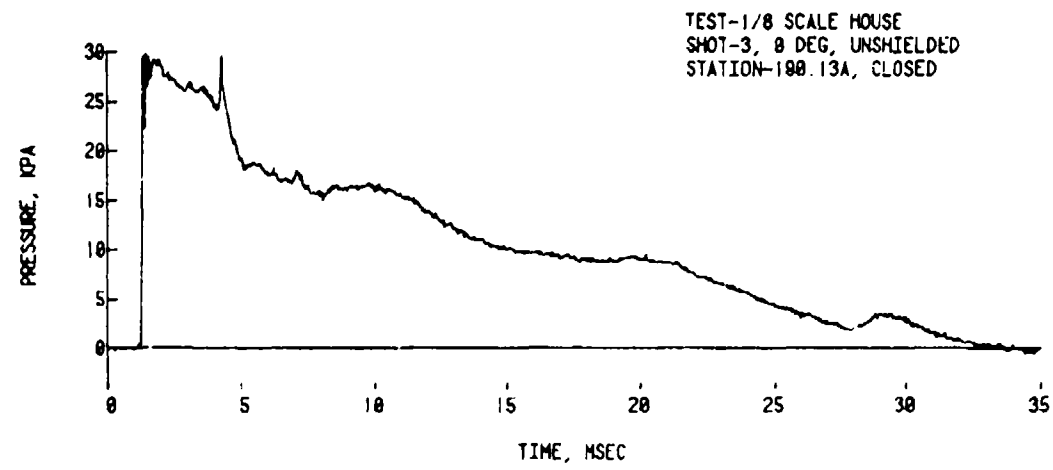


Figure 10. (Cont.) Pressure time records from Shot 3, unshielded model.

Table II. List of Parameters for Shot 3, Unshielded Model

Station	Location	Initial Peak* Overpressure, kPa	Maximum Peak Overpressure, kPa	Positive Overpressure Impulse, kPa-ms	Arrival Time, ms	Remarks
190.0A	Free-field	28.0	28.0	331	0.00	
1A	Front wall	61.4	61.4	380	0.00	P_1 = 93.0 kPa
2A	Front wall	63.2	63.2	370	0.00	T_1 = 299° K
3A	Front wall	57.7	60.0	380	0.00	
4A	Front wall	--	60.0	382	0.00	
5A	Front roof	61.3	61.3	375	0.10	Wind speed, 9 km/h
6A	Front roof	60.8	61.6	365	0.50	
7A	Rear roof	22.1	23.6	346	3.15	Test Site A, 0° orientation to blast wave with model closed.
8A	Rear roof	12.3	21.1	328	2.55	
9A	Rear wall	9.4	21.7	326	3.05	
10A	Rear wall	8.8	26.6	359	4.05	
11A	Rear wall	8.6	22.5	308	3.05	
12A	Rear wall	8.2	28.6	348	4.10	
13A	Left side wall	28.8	29.6	345	1.25	

*All peak overpressure values listed in Tables II - VII have been corrected for transducer overshoot and tape drop-outs.

B. In-Line Shielded Model

For Shot 2, uninstrumented shielding models were placed 1 m in front and 1 m behind the instrumented model. Figure 11 shows representative pressure-time records from the shot. All stations received some reflections from the shields superimposed upon the pressure-time records. Station 190.2A indicates a breakup of the initial rise time, caused by the front shield. The roof station, 190.6A, shows little change because of shields being present.

Both the rear roof and rear wall stations have enhanced loading at about 8-10 ms caused by the reflections from rear shield. The left side record was lost on this shot.

Table III lists the shot parameters for the in-line shielded model of Shot 2.

C. Model in 0° Complex, Closed Model

The twin of the model on Site A was installed on Site B for Shot 4 where it was placed in the model complex. The concrete pads of the complex were built so that the front wall of the instrumented model and shielding houses faced GZ. The angle of incidence between the blast wave and complex was zero for this shot. The blast wave was face-on to the front wall of the first row of shields. The free-field station, 190.0B, was still on a radial from GZ that was equal to the distance to the instrumented model's front wall from GZ.

Figure 12 shows records from the loading of the blast wave in Shot 4. There is a noticeable change in initial peak overpressure at Station 190.2B - down from the unshielded reflected value (Figure 10) of over 60 kPa (Shot 3) to about 40 kPa for this shot. The roof station again showed little change in the pressure record.

The most changes occurred on the rear roof, rear wall, and the left side wall. All received multiple reflections from the various shields making up the complex. Table IV lists the parameters for Shot 4.

D. Model in 45° Complex, Closed Model

Figure 13 summarizes the effects of the 45° complex at Site C. Arrival times change for all of the stations since the blast wave now has to travel to stations no longer equidistant, in the same plane with respect to the blast wave, as was true of 0° complex.

Multiple reflections again are present at all the stations. Station 190.15C on the left side of the model is now on a falling slope. The pressure-time record no longer looks similar to a free-field trace but is most similar to the trace from the rear wall station.

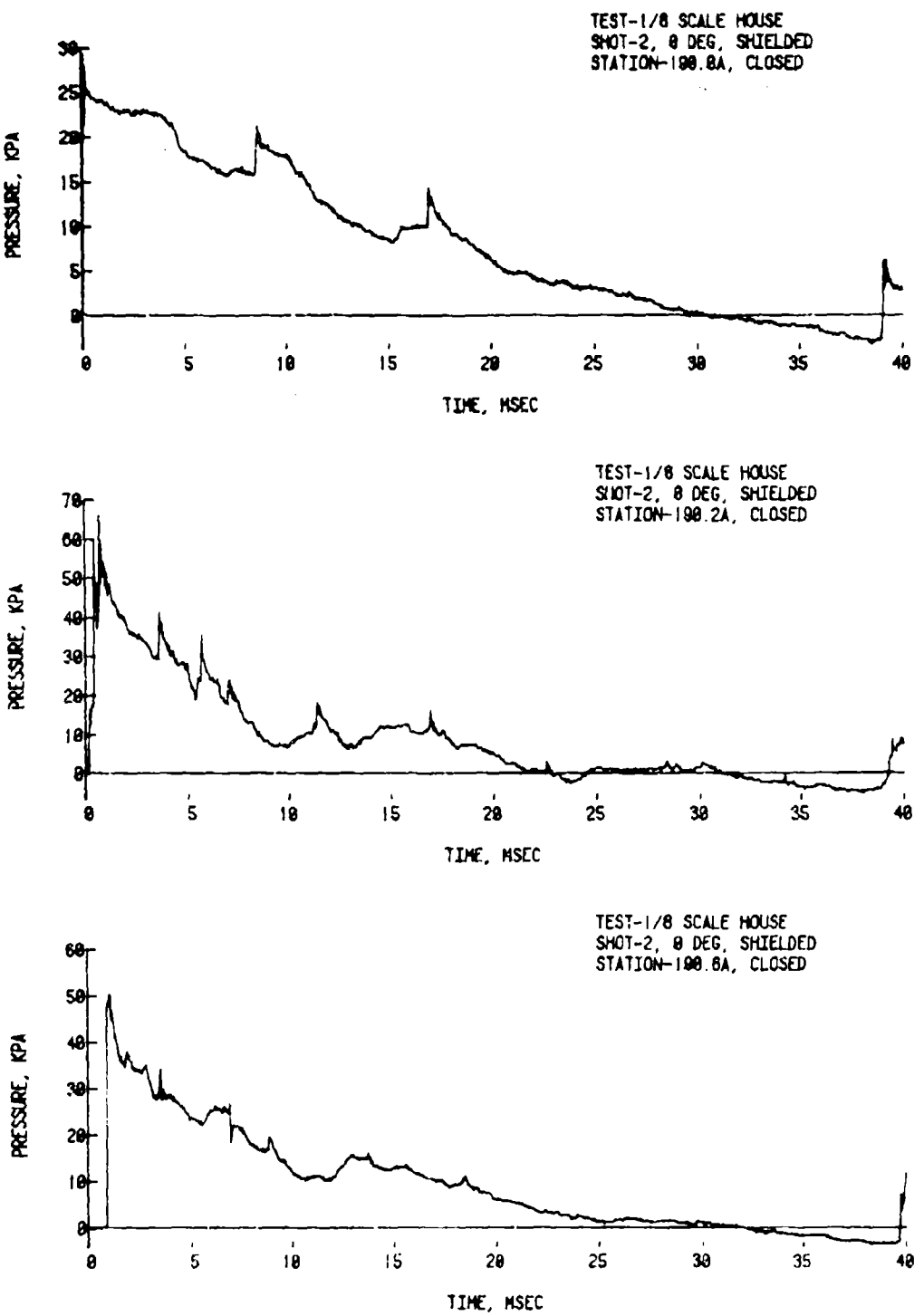


Figure 11. Pressure-time records from Shot 2, in the shielded model.

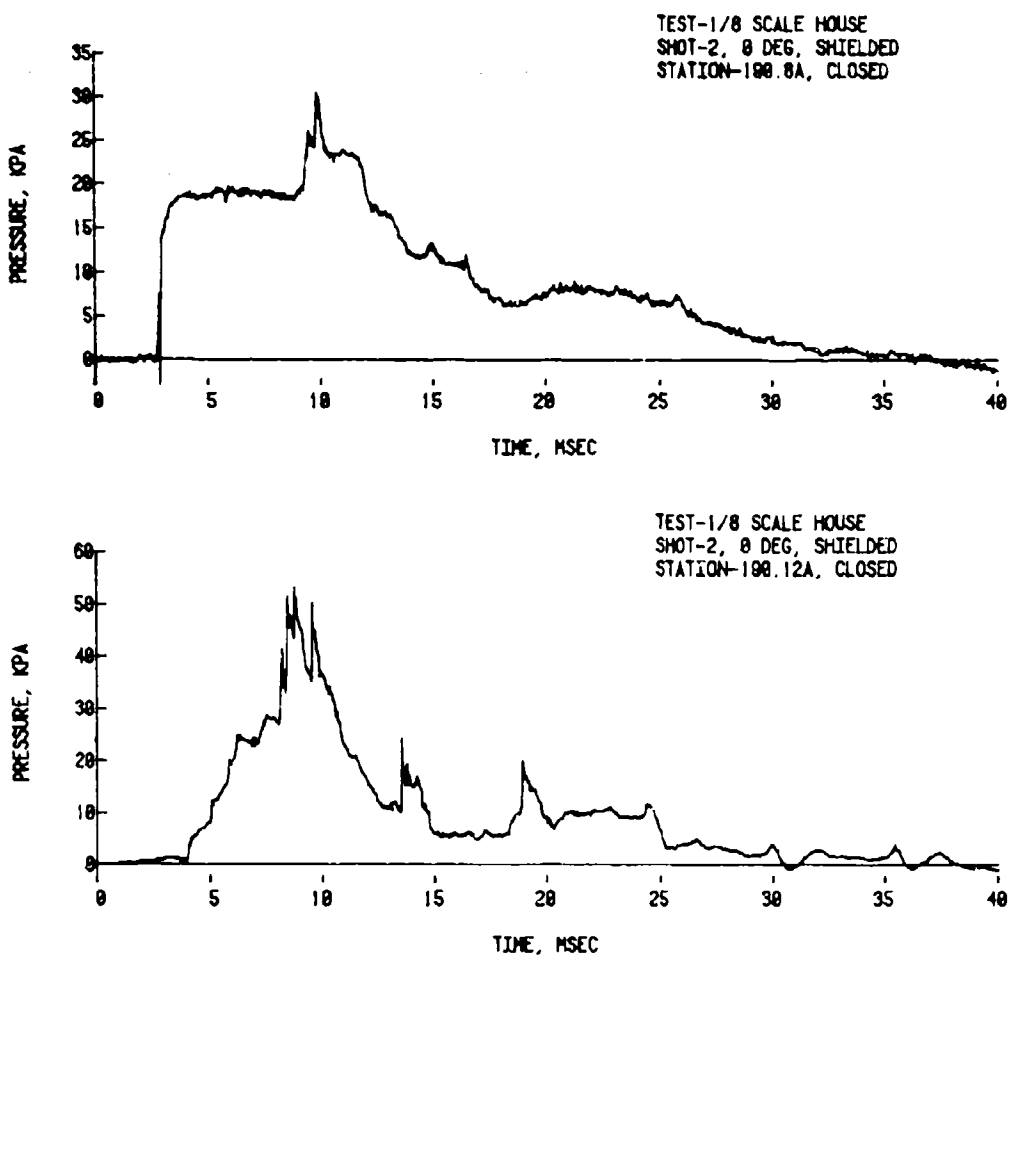


Figure 11. (Cont.) Pressure-time records from Shot 2, in-line shielded model.

Table III. List of Parameters for Shot 2, In-Line Shields

Station	Location	Initial Peak Overpressure, kPa	Maximum Peak Overpressure, kPa	Positive Overpressure Impulse, kPa-ms	Arrival Time, ms	Remarks
190.0A	Free-field	26.3	26.3	334	0.00	P_1 = 93.4 kPa
1A	Front wall	32.4	40.7	---	0.00	
2A	Front wall	14.3	57.4	364	0.15	T_1 = 288.4° K
3A	Front wall	24.9	50.1	379	0.00	
4A	Front wall	12.8	54.1	349	0.10	Wind speed, 8 km/h
5A	Front roof	51.2	51.2	361	0.45	
6A	Front roof	50.3	50.3	376	0.90	
7A	Rear roof	16.4	30.5	340	3.30	Test Site A, 0° orientation to blast wave with model closed.
8A	Rear roof	14.4	29.3	336	2.90	
9A	Rear wall	4.6	34.3	311	3.10	
10A	Rear wall	3.4	46.1	345	4.35	
11A	Rear wall	5.6	44.4	330	3.10	
12A	Rear wall	3.2	52.1	356	4.10	
13A	Left side wall	19.3	29.5	---	0.45	

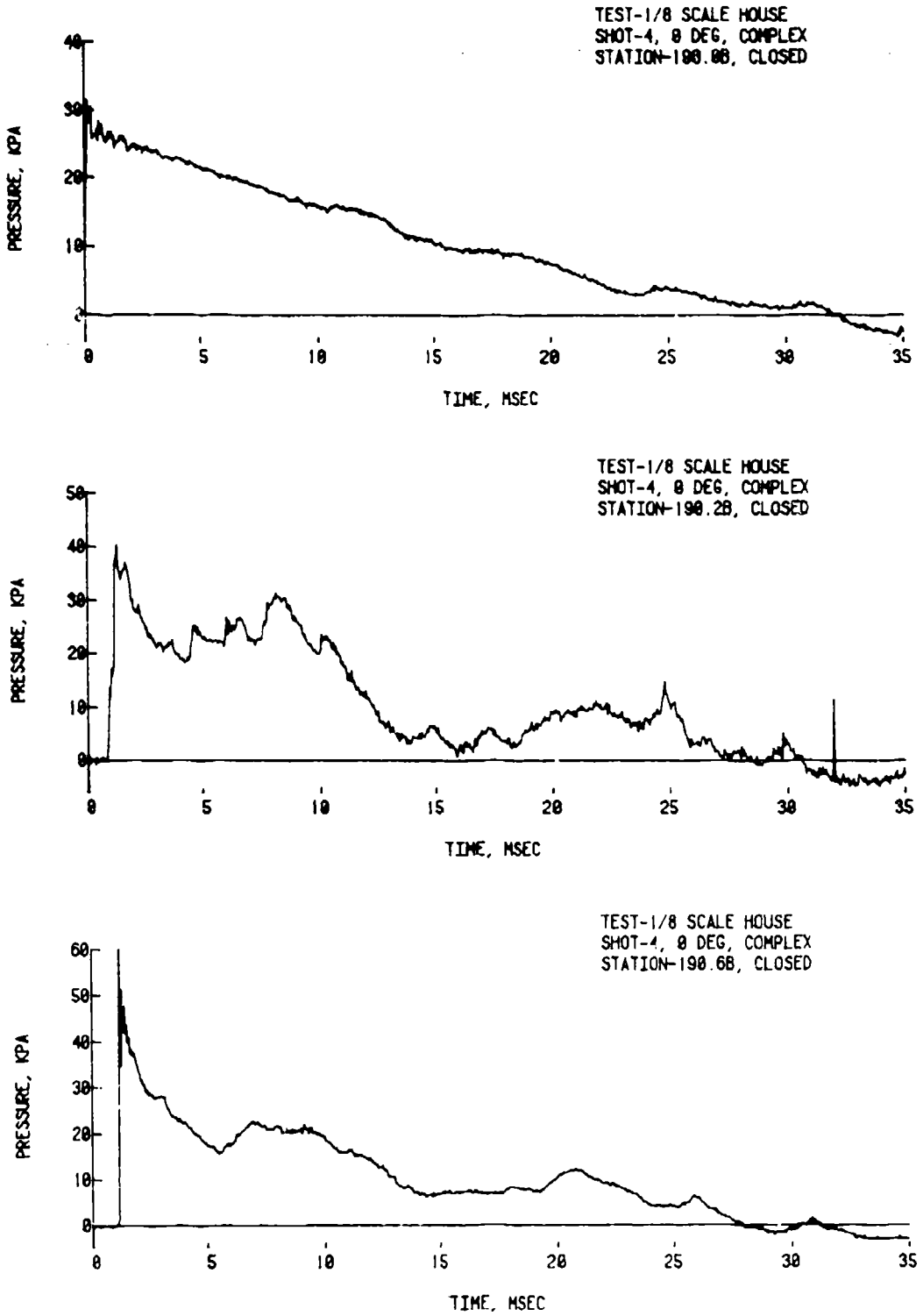


Figure 12. Pressure-time records from Shot 4, scaled, closed, 0°, complex.

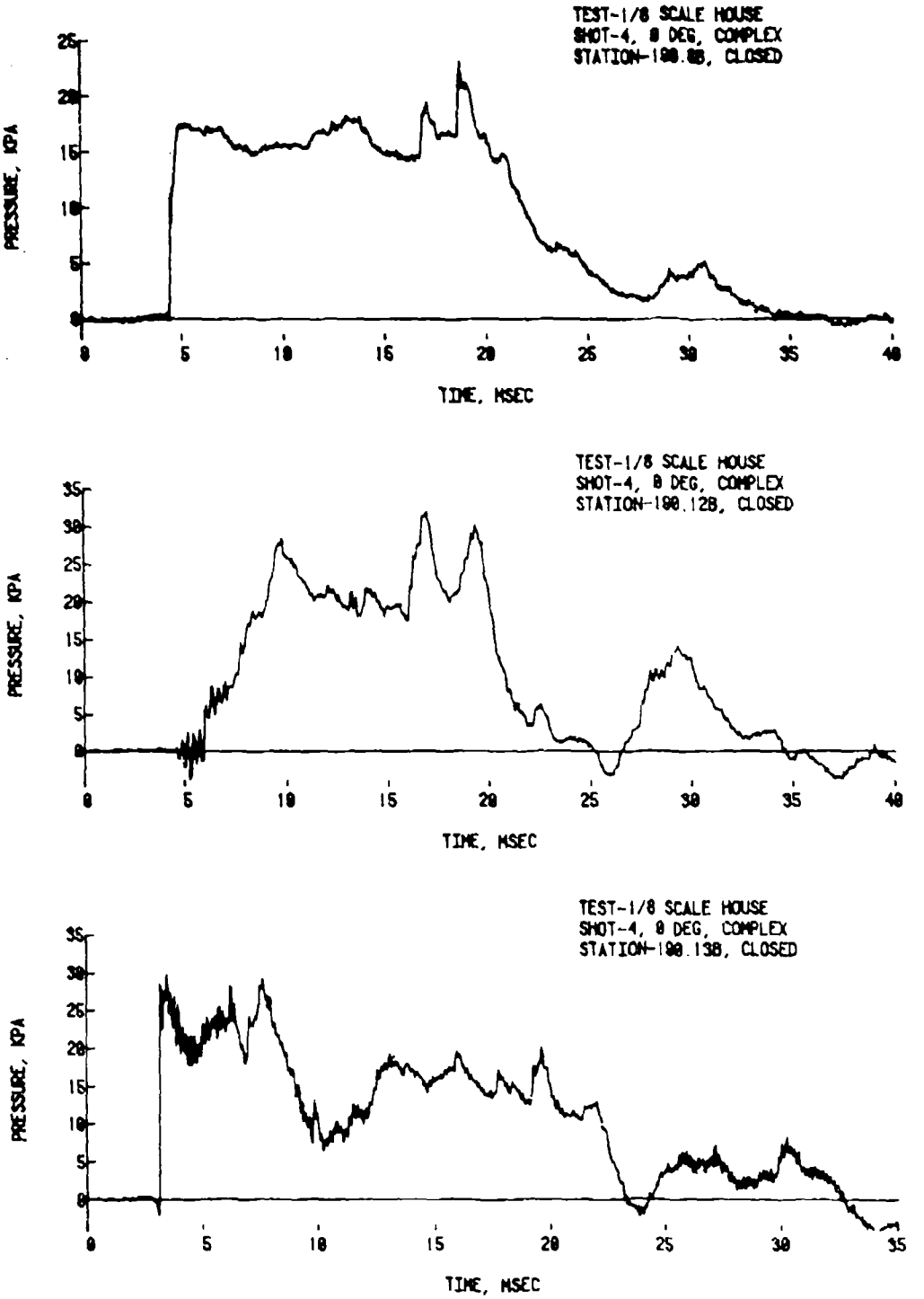


Figure 12. (Cont) Pressure-time records from Shot 4, model closed - 0° complex.

Table IV. List of Parameters for Shot 4, Model Closed - 0° Complex

Station	Location	Initial Peak Overpressure, kPa	Maximum Peak Overpressure, kPa	Positive Overpressure Impulse, kPa-ms	Arrival Time, ms	Remarks
190.0A	Free-field	26.0	26.0	324	0.00	
4A	Front wall	--	60.0	380	0.00	P_1 = 93.3 kPa
6A	Front roof	--	60.0	364	0.35	T_1 = 303.8° K
190.0B	Free-field	28.0	28.0	358	0.00	
1B	Front wall	25.1	39.3	351	0.55	Wind speed, 6.4 km/h
2B	Front wall	12.6	40.5	346	0.90	
3B	Front wall	27.2	32.5	339	0.55	
4B	Front wall	15.9	34.7	303	0.90	Test Site B, 0° orientation to blast wave in complex with model closed.
5B	Front roof	46.4	46.4	376	0.80	
6B	Front roof	51.0	51.0	351	1.15	
7B	Rear roof	15.2	22.9	309	5.05	
8B	Rear roof	10.0	21.7	328	4.45	
9B	Rear wall	5.6	25.1	315	4.90	
10B	Rear wall	5.9	28.5	326	5.95	
11B	Rear wall	--	30.9	312	4.90	
12B	Rear wall	5.3	32.0	351	5.95	
13B	Left side wall	27.0	28.1	351	3.15	

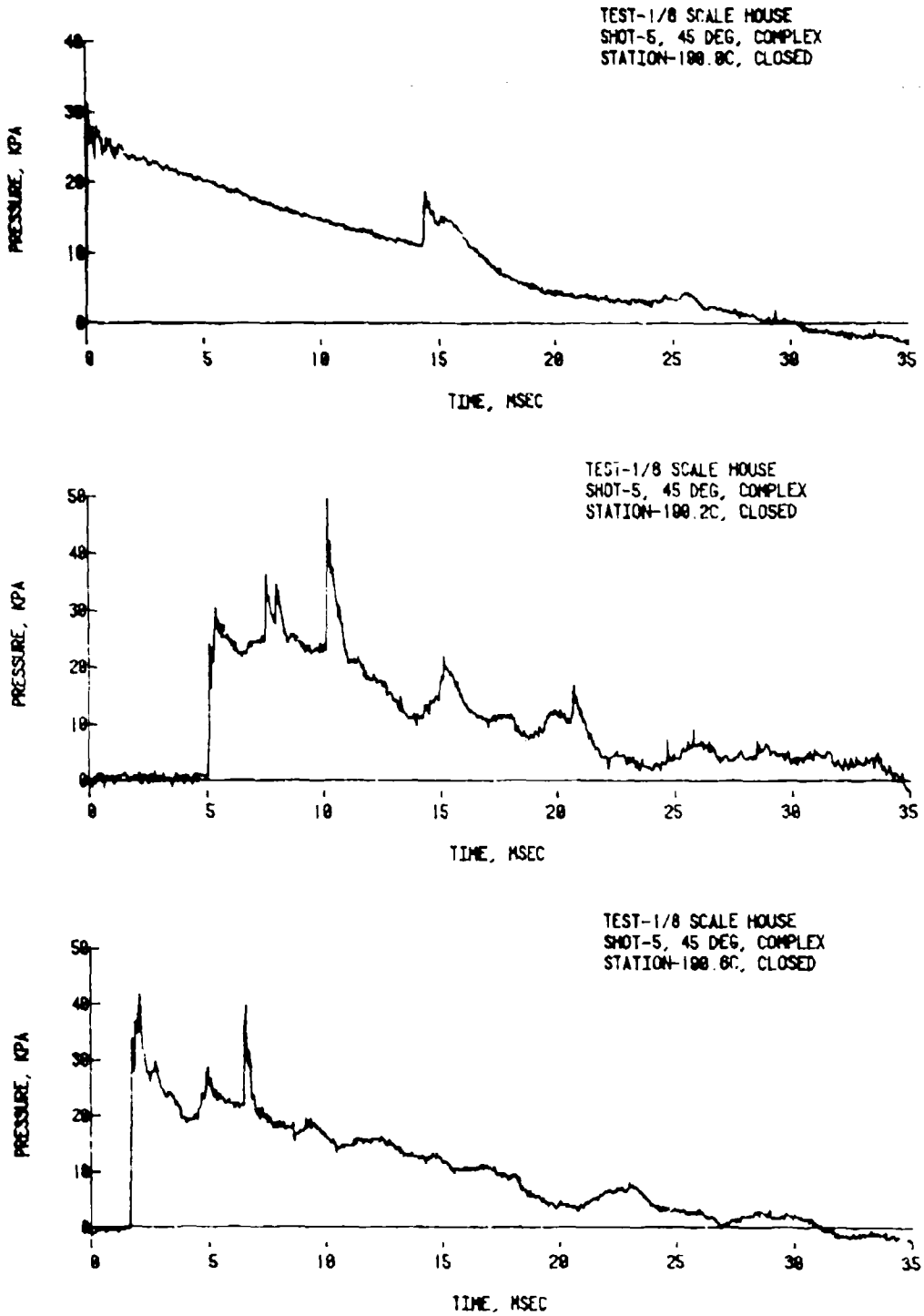
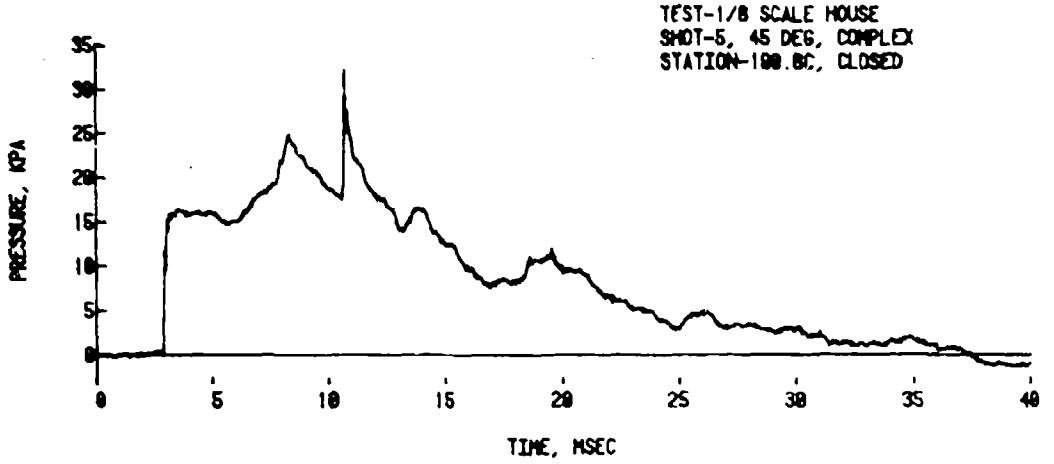
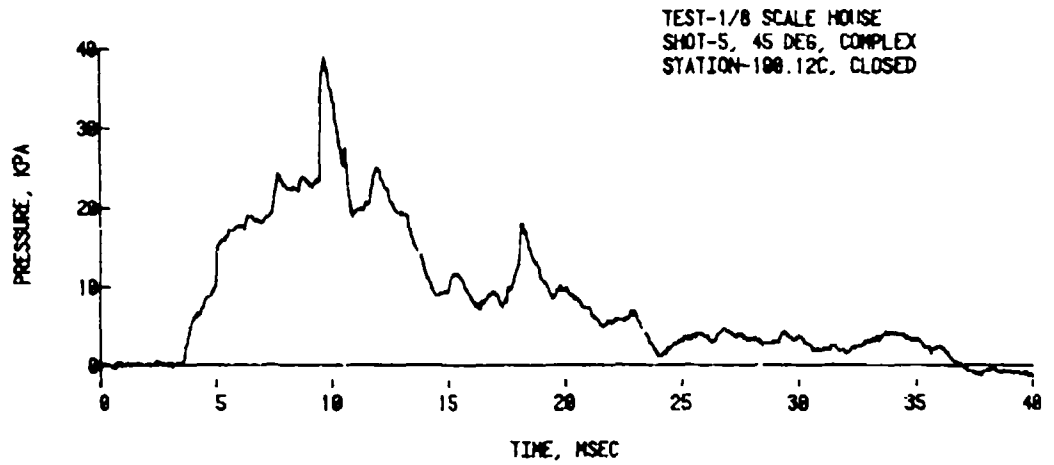


Figure 15. Pressure-time records from Shot 5, model closed - 45 complex.





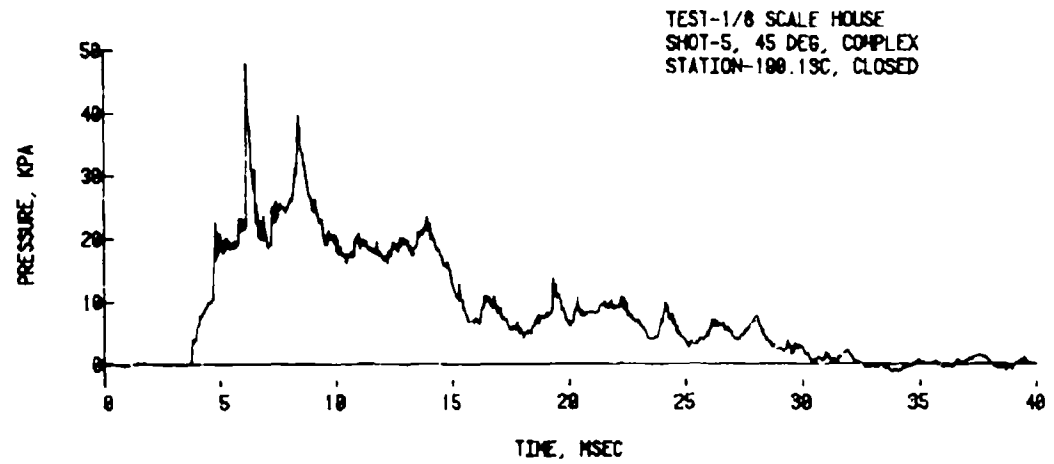


Figure 15. (Cont.) Pressure time records from Shot 5, model closed - 45° complex.

Table V lists the parameters from the data taken from the model in the 45° complex.

E. Model in 45° Complex, Open Model

The instrumented house models had a door and several windows cut into the walls to prepare for Shots 6 and 7. The complex remained on Site C for Shot 6 and then the complete complex was moved back to Site B (0°) for the final shot of the test series. Figure 14 shows representative pressure-time traces for Shot 6. Records from stations on the outside of the model were only slighty different from outside records from the previous shot.

Stations 190.5A1 and 190.5CI are similar in that the peak pressures at 7 ms are both lower than the outside free-field pressure. The pressure profile at Station 190.5CI seems to have a somewhat longer positive duration than does the record from the unshielded station at 190.5AI. The reflections coming from the rear model shields appear to fill in through the attic windows. This gives an increased pressure which adds to the undisturbed free-field input loading pressure at the attic openings.

Table VI lists parameters for Shot 6.

F. Model in 0° Complex, Open Model

As in Shot 6, Shot 7 (Figure 15) shows similar outside effects as with the closed model in the 0° complex. The two inside stations, 190.5CI and 190.7CI, exhibited similar pressure-time traces as did the 45° complex interior stations. These and the effects at other stations are summarized in Table VII.

IV. ANALYSIS

This section will compare pressure-time traces as a function of the orientation of the blast wave to the model, or complex, to determine the effectiveness of the shielding configurations tested.

A. Blast Wave at Normal Incidence

Pressure-time records from the shots taken at normal incidence to the blast wave will be compared to determine effectiveness of the shielding when at 0° incidence. Figures 16 - 21 illustrate the types of loading records measured at the various walls and roof of the model for each of the free-field blast waves.

Table V. List of Parameters for Shot 5, Model Closed - 45° Complex

Station	Location	Initial Peak Overpressure, kPa	Maximum Peak Overpressure, kPa	Positive Overpressure Impulse, kPa-ms	Arrival Time, ms	Remarks
190.0A	Free-field	24.8	24.8	314	0.00	
4A	Front wall	52.0	57.7	359	0.00	P_1 = 92.4 kPa
6A	Front roof	--	53.1	338	0.40	
12A	Rear wall	3.5	23.7	286	4.00	T_1 = 301.9° K
190.0C	Free-field	27.2	27.2	337	0.00	
1C	Front wall	27.6	45.0	339	2.00	Wind speed, 4.8 km/h
2C	Front wall	22.1	42.1	349	5.10	
3C	Front wall	47.5	47.5	317	2.70	
4C	Front wall	39.2	53.8	332	2.00	
5C	Front roof	15.2	23.3	202	1.50	Test Site C, 45° orientation to blast wave in complex with model closed.
6C	Front roof	30.8	41.5	336	1.65	
7C	Rear roof	12.7	26.4	323	3.15	
8C	Rear roof	10.5	29.6	319	2.85	
9C	Rear wall	10.5	31.5	323	4.35	
10C	Rear wall	9.8	37.8	332	3.55	
11C	Rear wall	2.5	31.9	324	4.60	
12C	Rear wall	1.3	38.9	323	3.55	
13C	Left side wall	3.4	47.8	329	3.80	

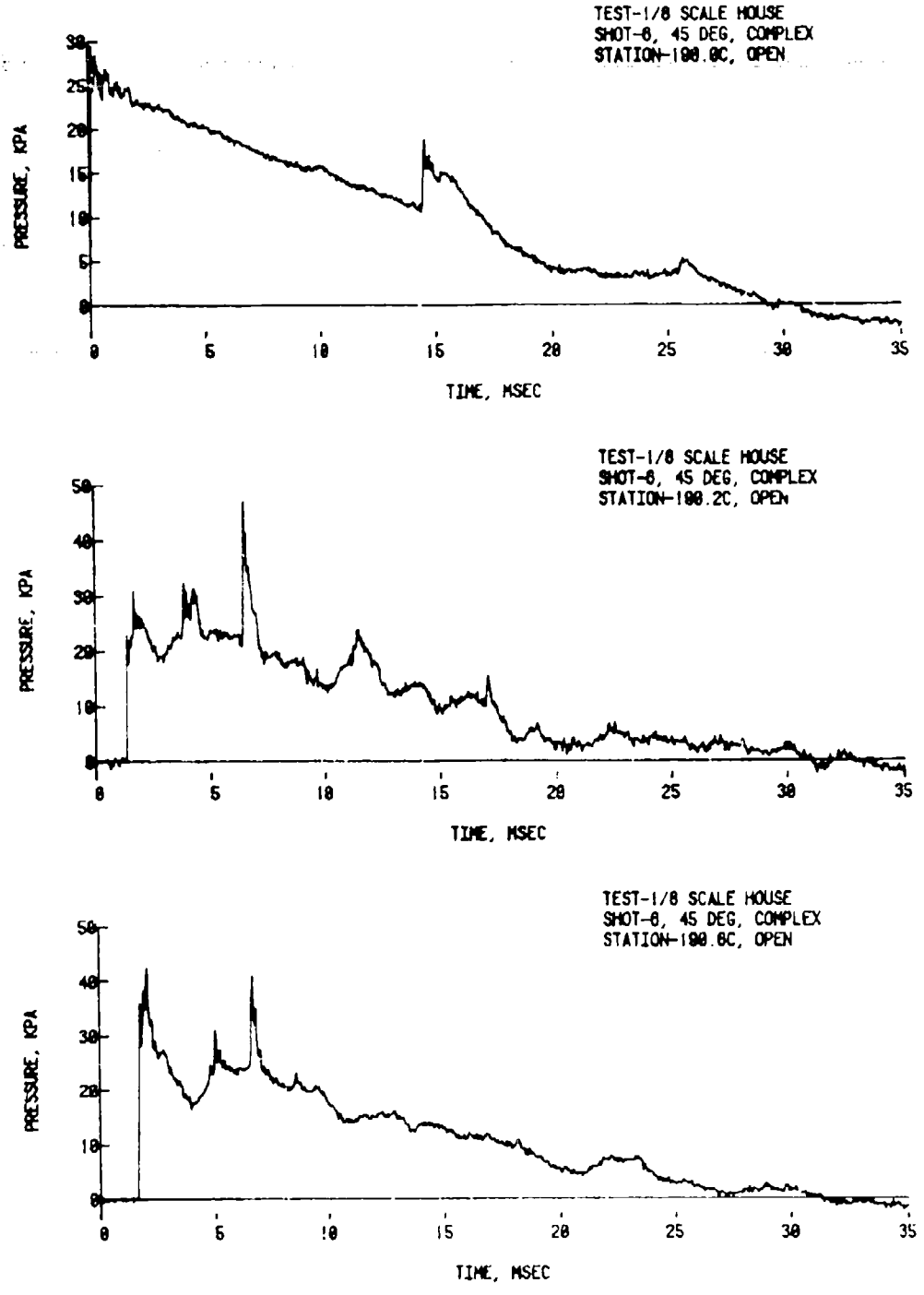
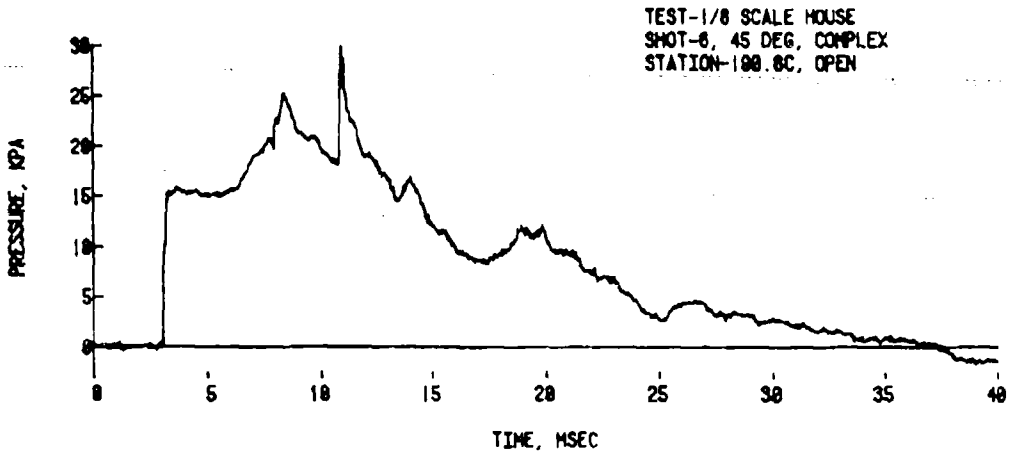
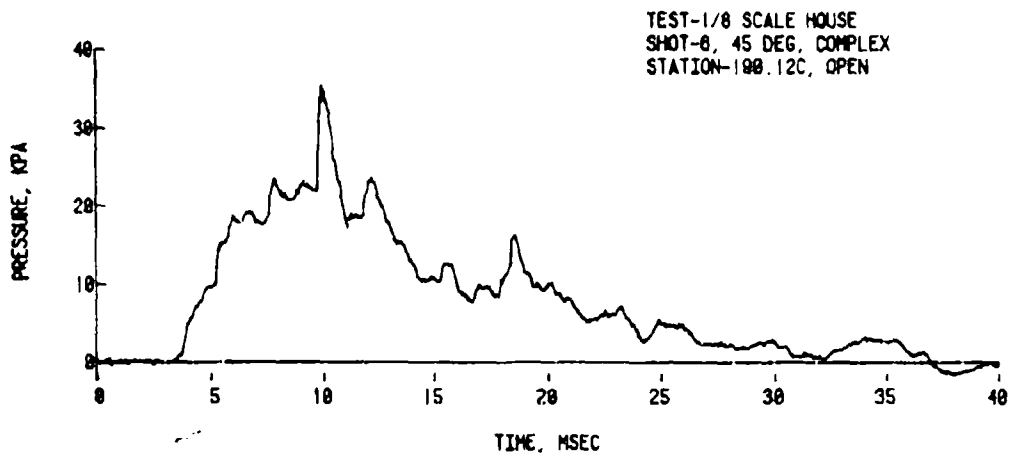


Figure 14. Pressure-time records from Shot 6, model open - 45° complex.





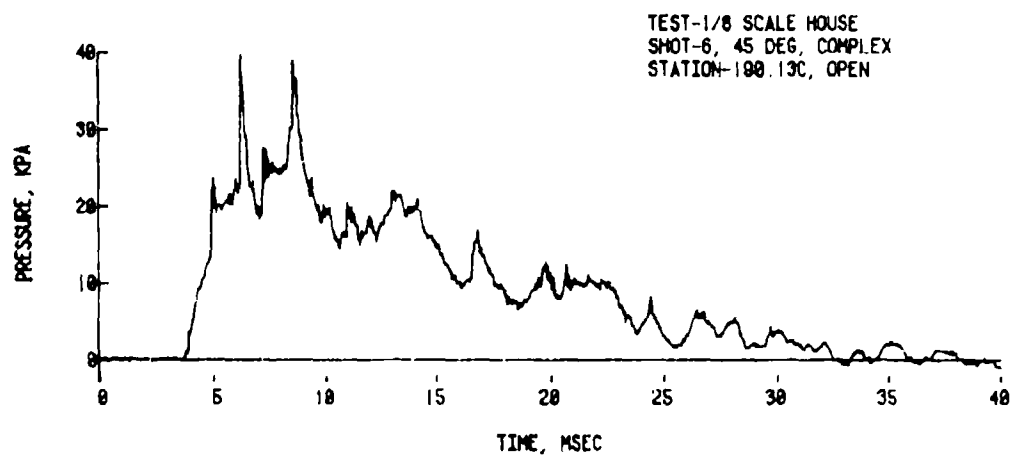
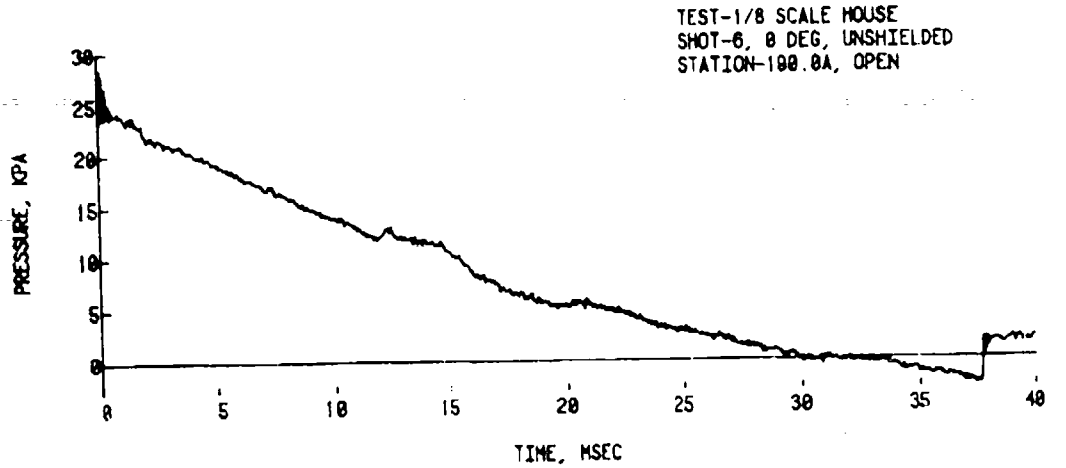
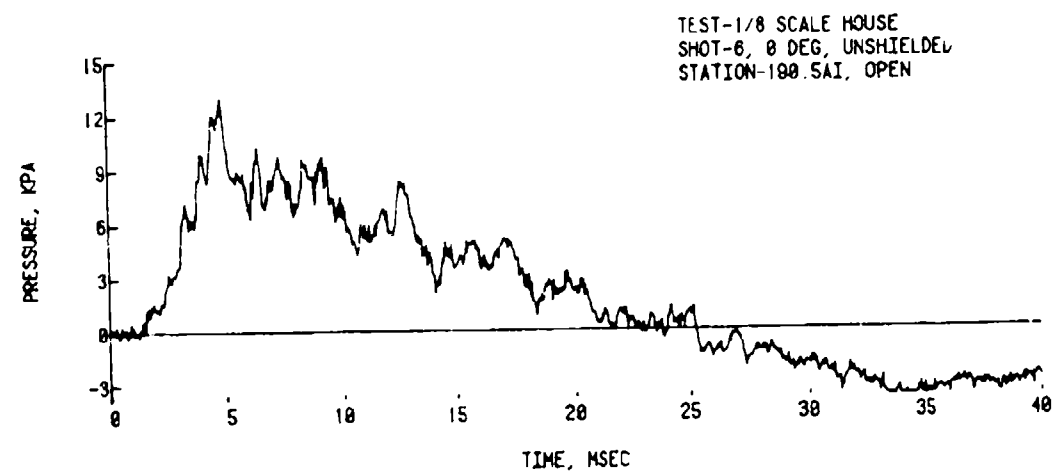


Figure 14. (Cont) Pressure-time records from Shot 6, model open - 45° complex.





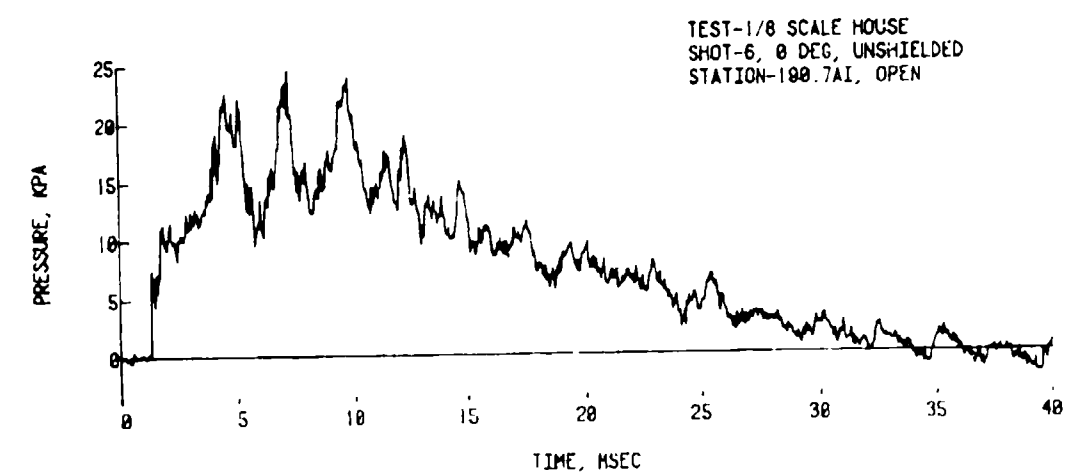
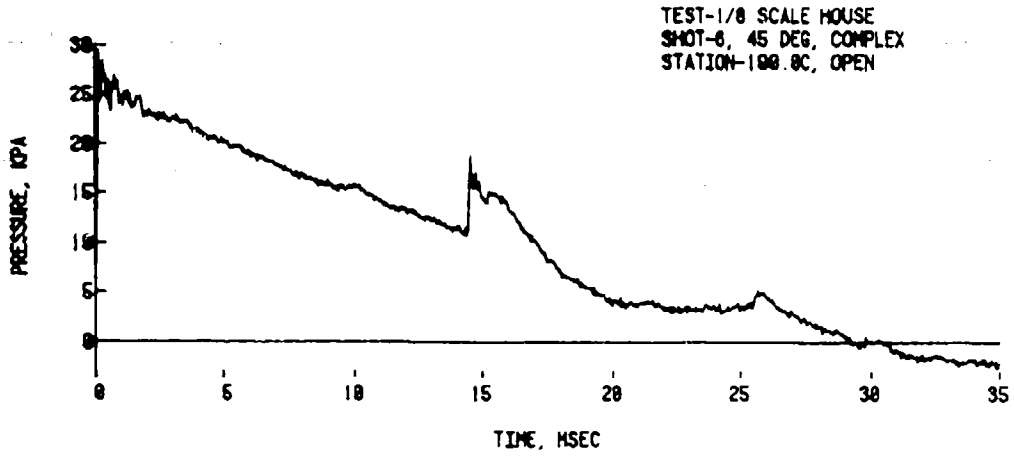
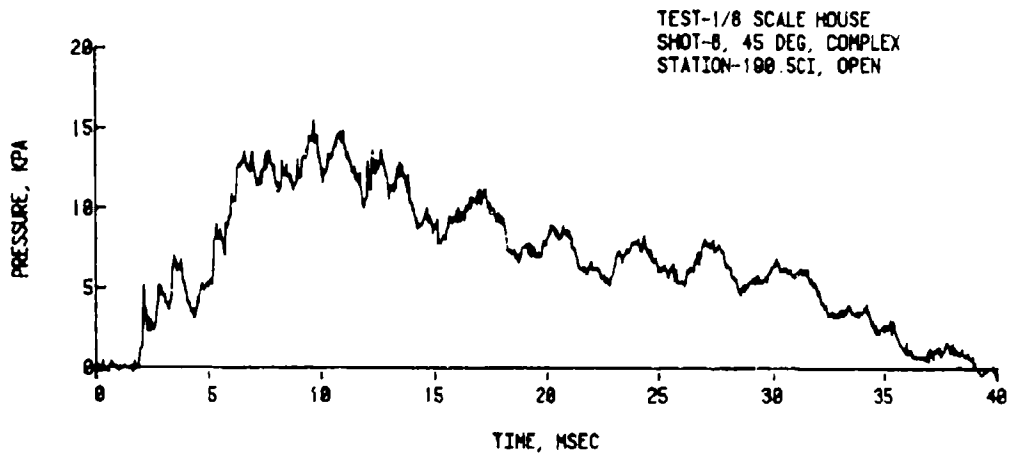


Figure 11. (Cont.) Pressure-time records from Shot 6, model open 45° complex.





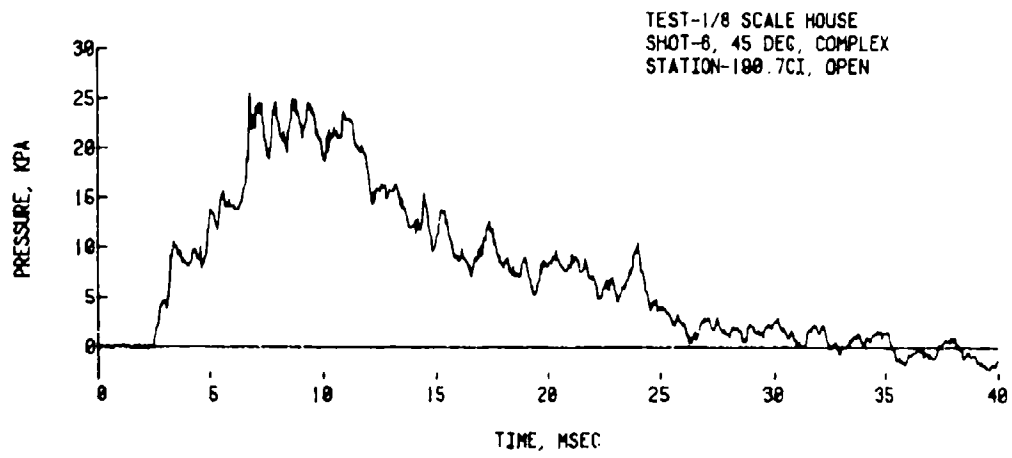


Figure 11. (cont) Pressure-time records from Shot 6, model open - 45° complex.

Table VI. List of Parameters for Shot 6, Model Open - 45° Complex

Station	Location	Initial Peak Overpressure, kPa	Maximum Peak Overpressure, kPa	Positive Overpressure Impulse, kPa-ms	Arrival Time, ms	Remarks
190.0A	Free-field	26.0	26.0	318	0.00	
4A	Front wall	56.7	56.7	376	0.00	P_1 = 93.4 kPa
5AI	Attic	<1.0	13.0	---	1.60	
6A	Front roof	57.7	57.7	352	0.50	T_1 = 297.3° K
7AI	Ground floor	6.6	23.9	296	1.35	
12A	Rear wall	<1.0	23.0	310	3.15	Wind speed, 4 km/h
190.0C	Free-field	27.2	27.2	342	0.00	
1C	Front wall	15.0	44.8	339	2.10	
2C	Front wall	20.6	41.8	336	1.45	
3C	Front wall	30.2	42.2	308	2.75	Test Site C, 45° orientation to blast wave in complex with model open.
4C	Front wall	34.6	47.4	340	2.00	
5CI	Attic	5.6	14.8	---	2.00	
6C	Front roof	51.8	38.8	354	1.75	
7CI	Ground floor	1.8	25.0	297	2.60	
8C	Rear roof	10.1	28.6	328	3.05	
9C	Rear wall	2.9	30.0	326	4.00	
10C	Rear wall	3.6	38.0	341	3.40	
11C	Rear wall	<1.0	30.9	333	4.20	
12C	Rear wall	1.0	34.6	309	3.50	
13C	Left side wall	1.0	39.6	339	3.85	

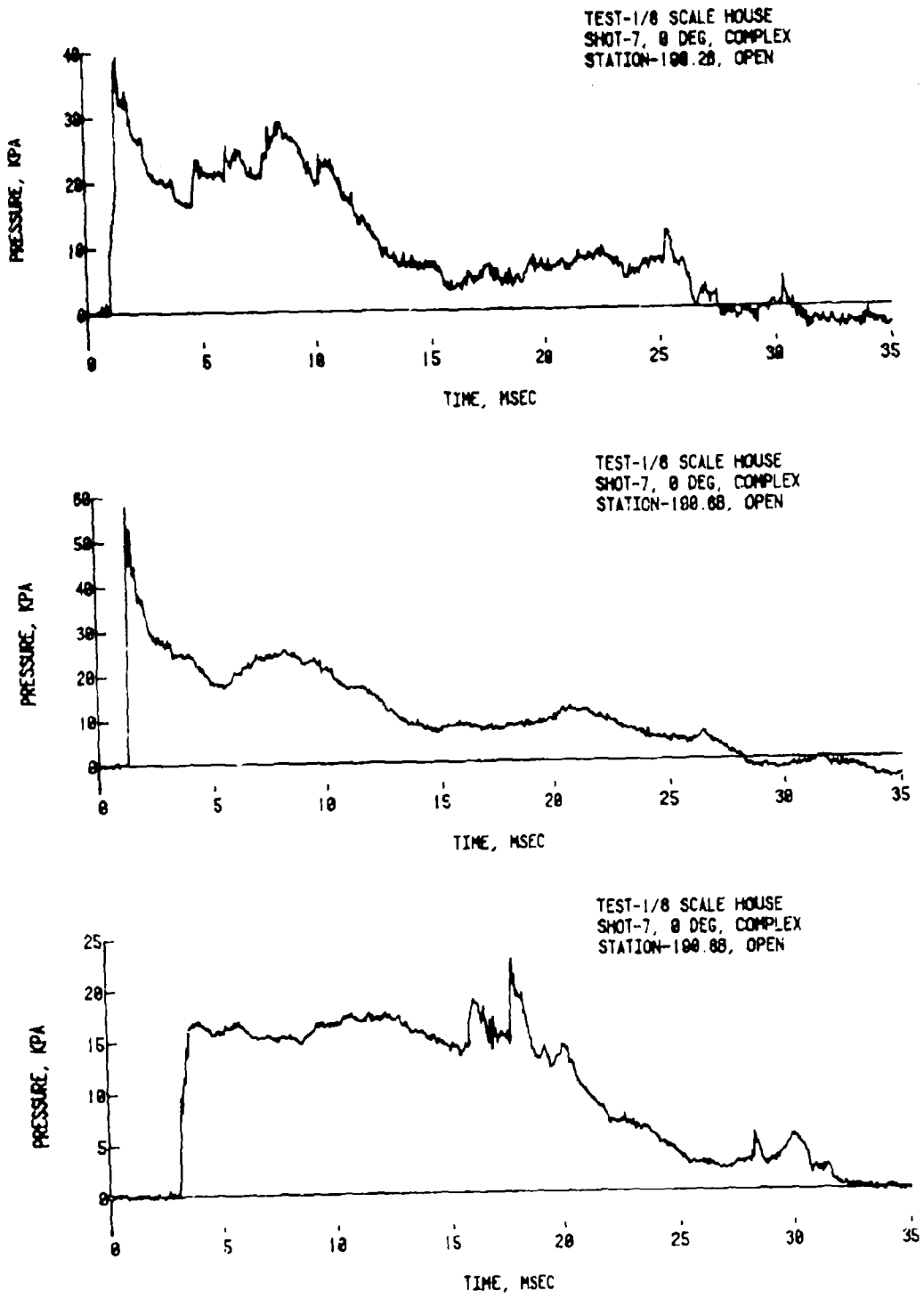


Figure 15. Pressure-time records from Shot 7, model open - 0° complex.

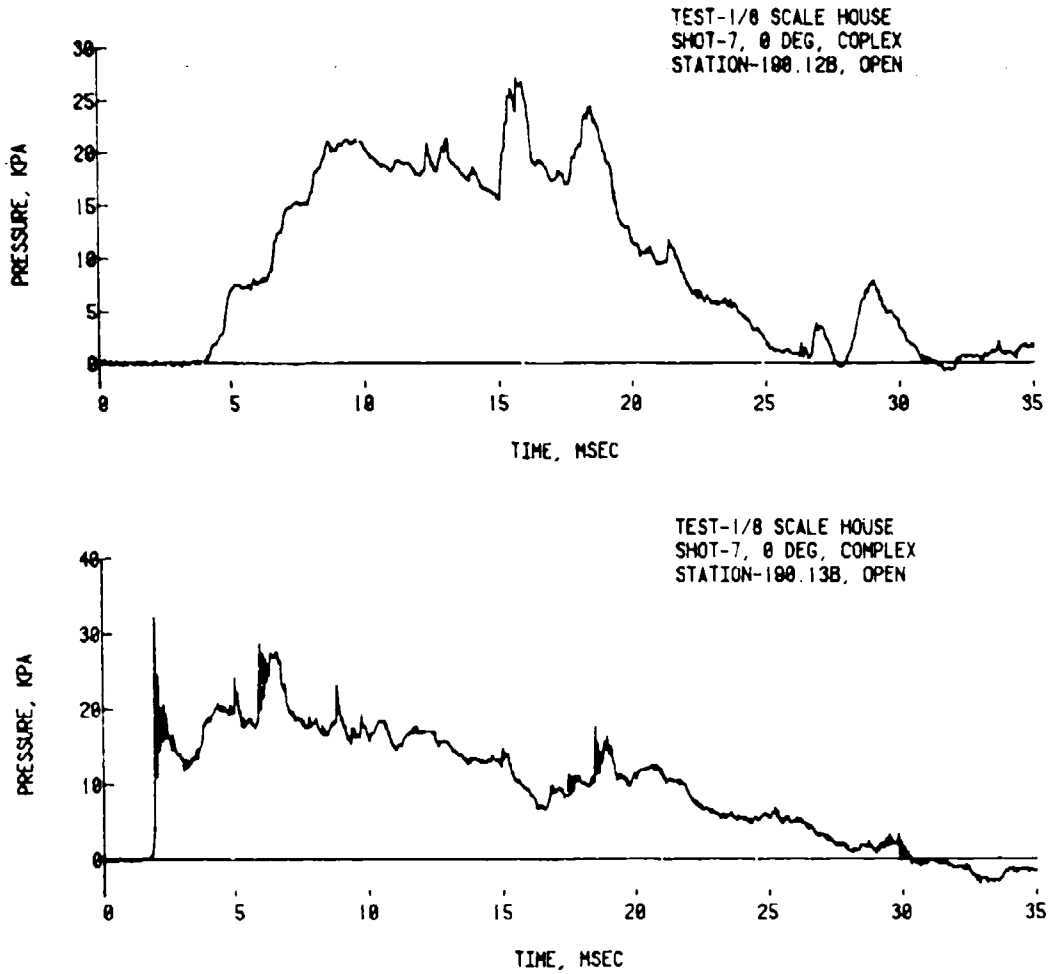


Figure 15. (Cont.) Pressure time records from Shot 7, model open 0° complex.

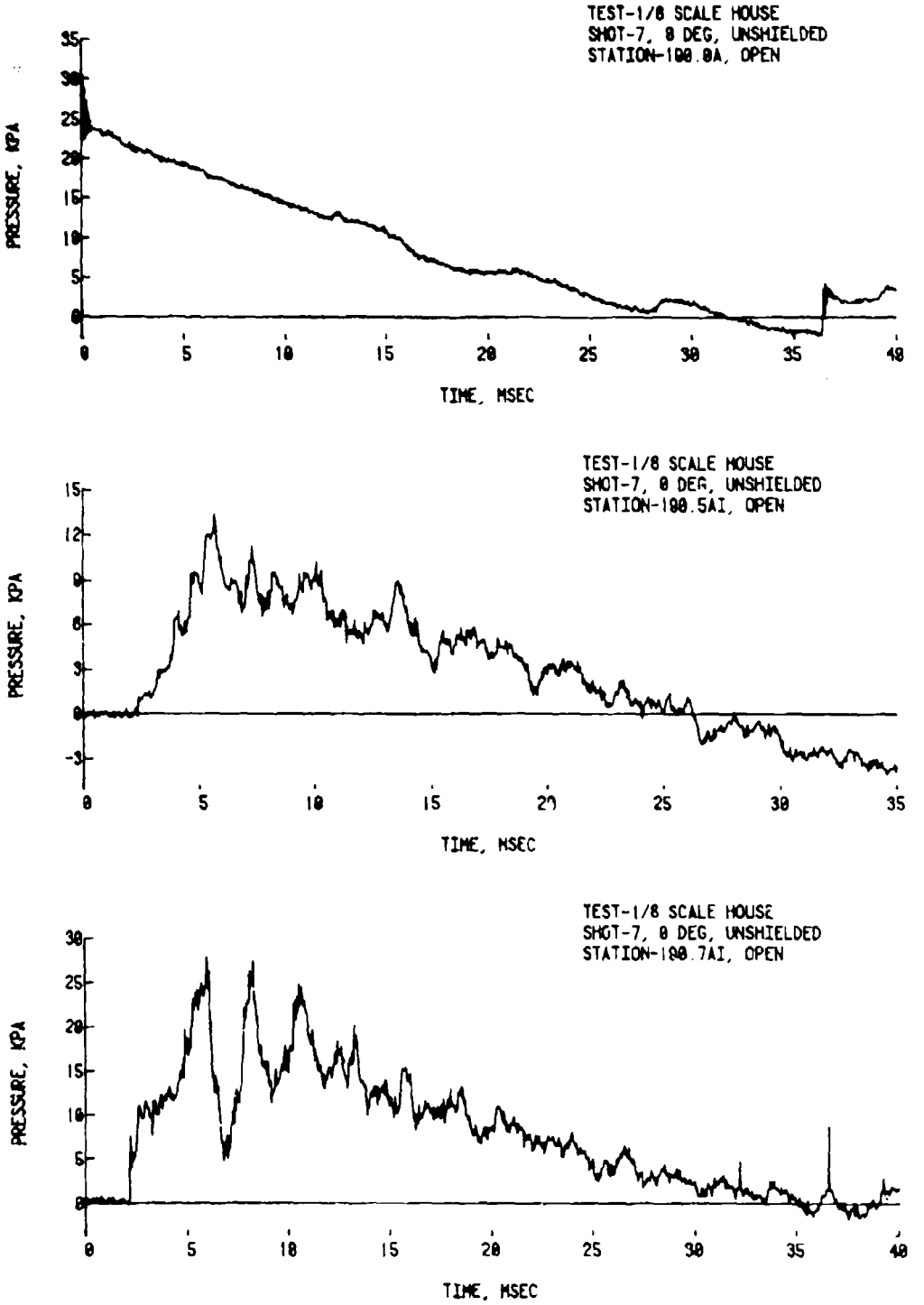


Figure 15. (Cont) Pressure-time records from Shot 7, model open - 0° complex.

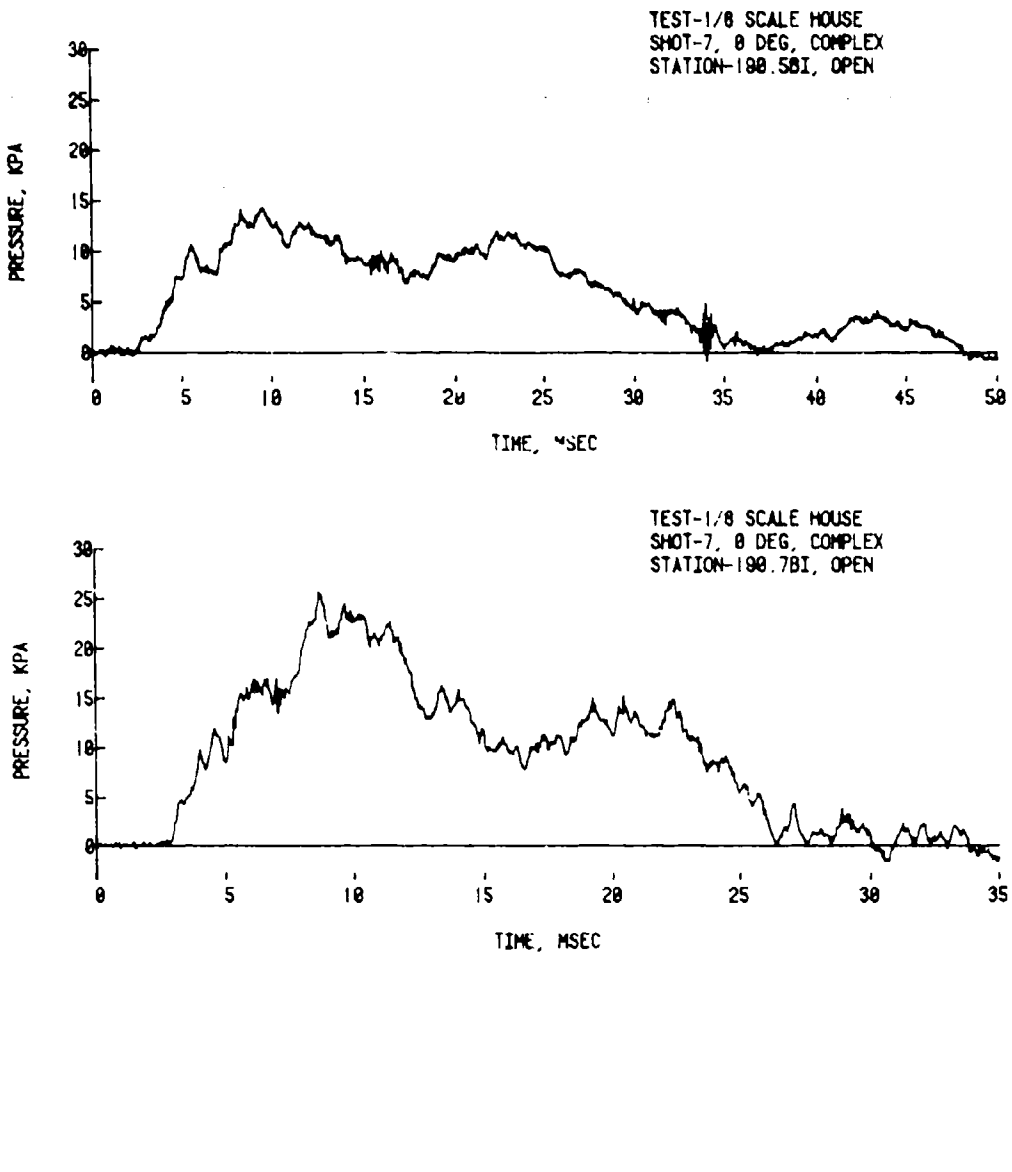


Figure 15. (Cont.) Pressure-time records from Shot 7, model open - 0° complex.

Table VII. List of Parameters for Shot 7, Model Open - 0° Complex

Station	Location	Initial Peak Overpressure, kPa	Maximum Peak Overpressure, kPa	Positive Overpressure Impulse, kPa-ms	Arrival Time, ms	Remarks
190.0A	Free-field	26.2	26.2	326	0.00	
4A	Front wall	57.2	57.2	353	0.00	P_1 = 94.1 kPa
5AI	Attic	1.0	12.4	290	2.35	
6A	Front roof	56.1	56.1	365	0.50	T_1 = 290.8° K
7AI	Ground floor	5.3	26.9	310	2.15	
12A	Rear wall	<1.0	22.5	302	2.45	Wind speed, 9.2 km/h
190.1B	Front wall	21.7	32.1	376	0.60	
2B	Front wall	9.2	39.3	345	1.00	
3B	Front wall	21.7	30.0	338	0.60	
4B	Front wall	14.2	31.9	317	0.95	Test Site B, 0° orientation to blast wave in complex with model open.
5BI	Attic	<1.0	14.2	288	2.50	
6B	Front roof	52.2	52.2	380	1.25	
7BI	Ground floor	<1.0	25.6	314	2.95	
8B	Rear roof	8.8	22.7	324	3.20	
9B	Rear wall	10.0	20.9	298	3.65	
10B	Rear wall	3.6	25.4	324	4.05	
11B	Rear wall	8.4	24.8	295	3.65	
12B	Rear wall	1.8	26.0	322	4.05	
13B	Left side wall	17.8	27.3	335	1.95	

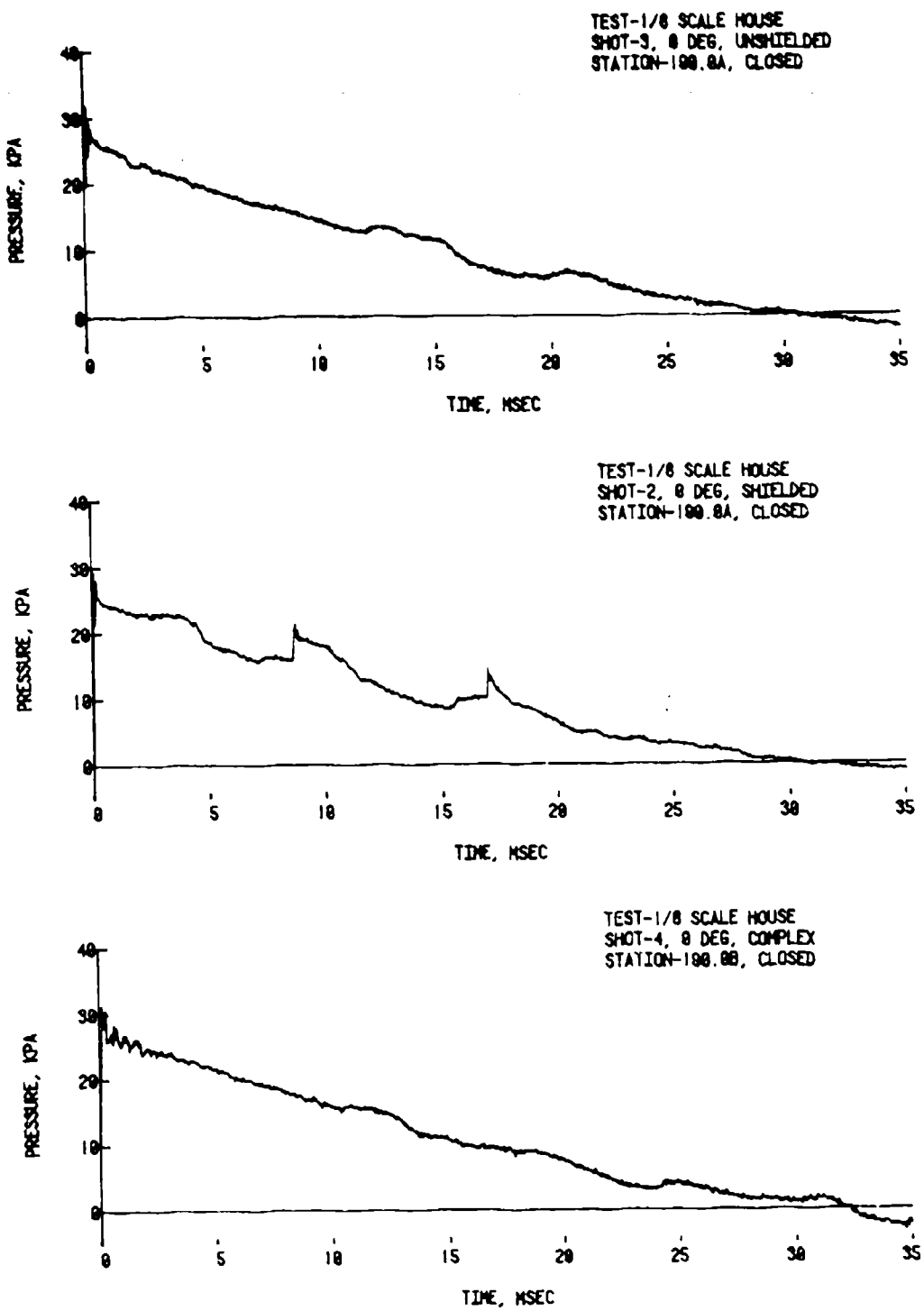
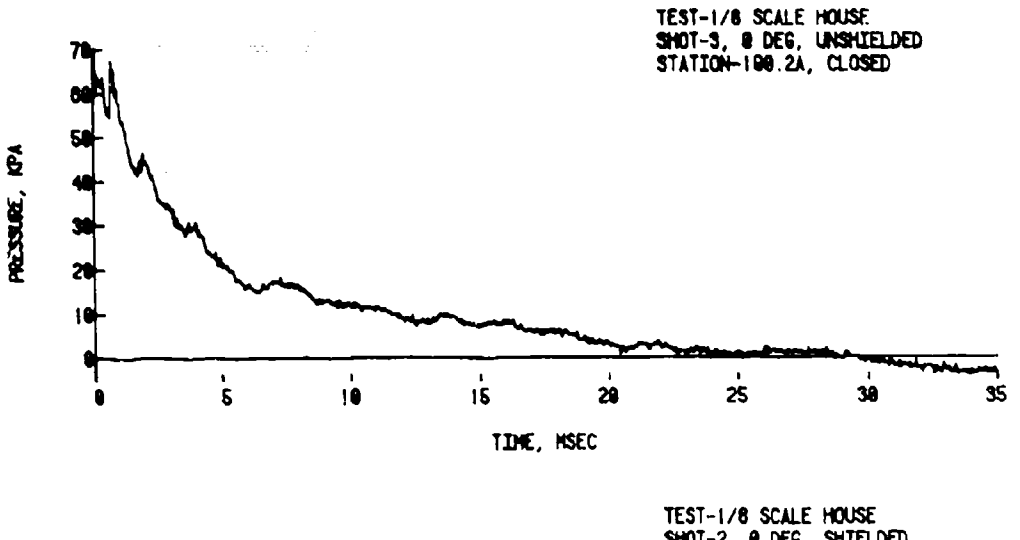
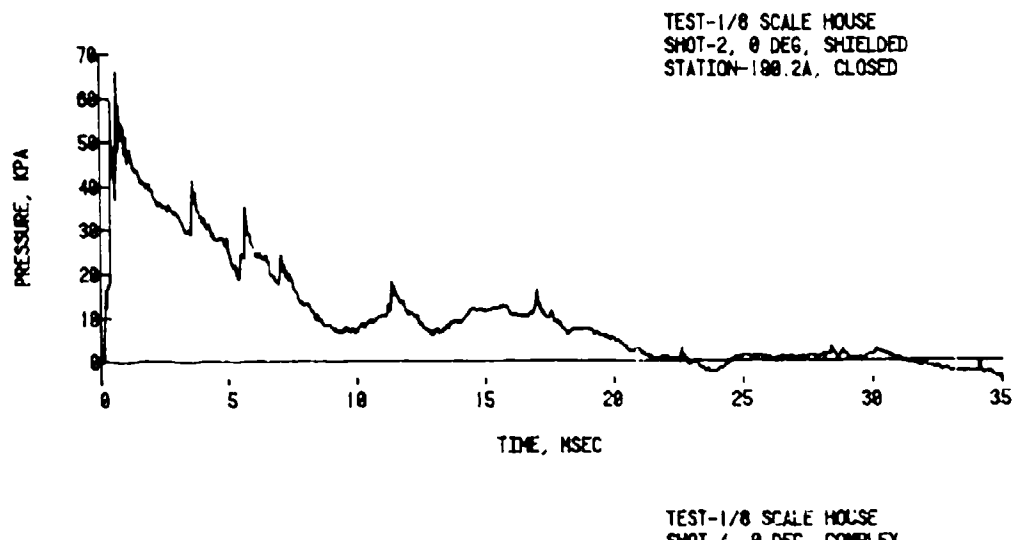


Figure 16. Comparison of free-field blast waves for Shots 2, 3, and 4.





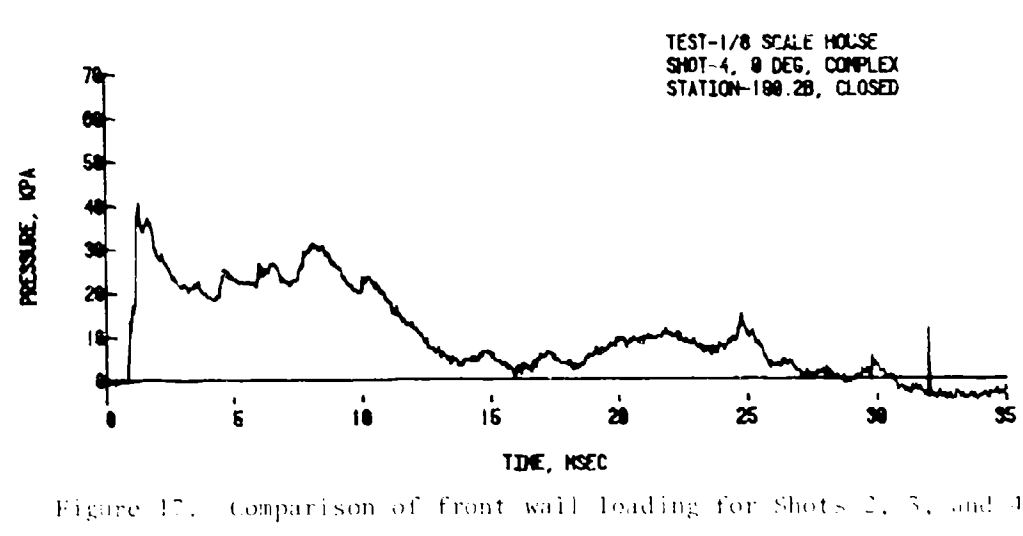
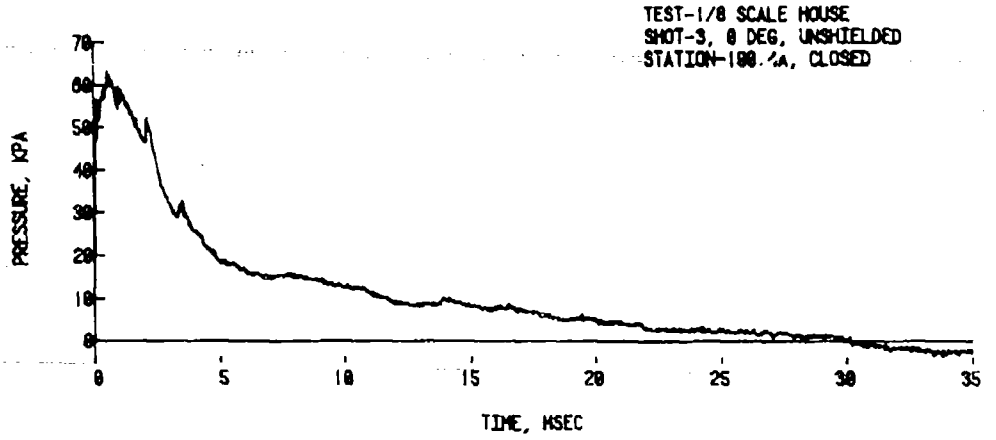
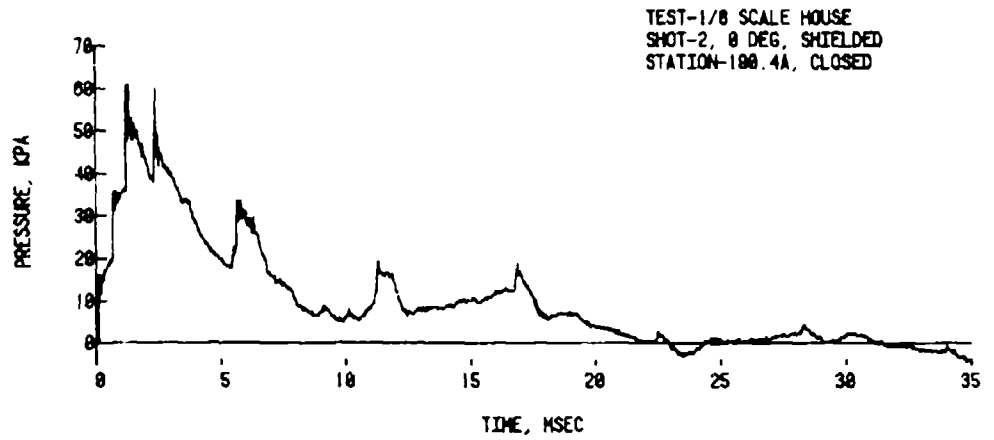


Figure 17. Comparison of front wall loading for Shots 2, 3, and 4.





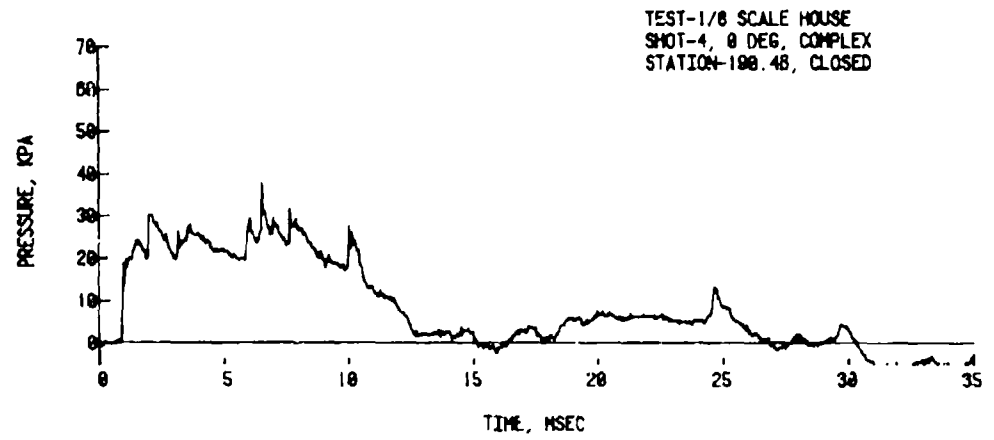


Figure 17. (cont.) Comparison of front wall loading for Shots 2, 3, and 4.

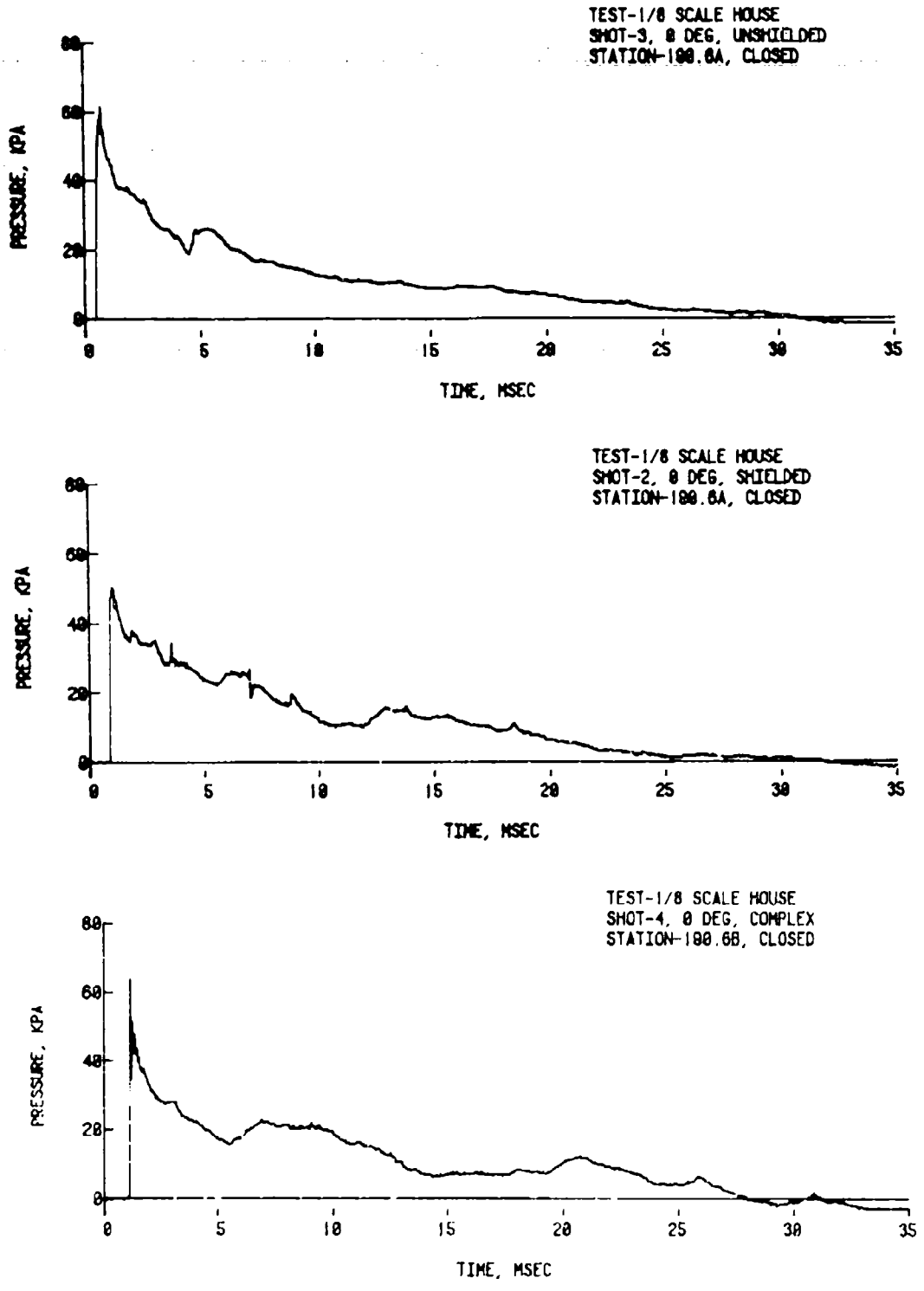


Figure 18. Comparison of front roof loading for Shots 2, 3, and 4.

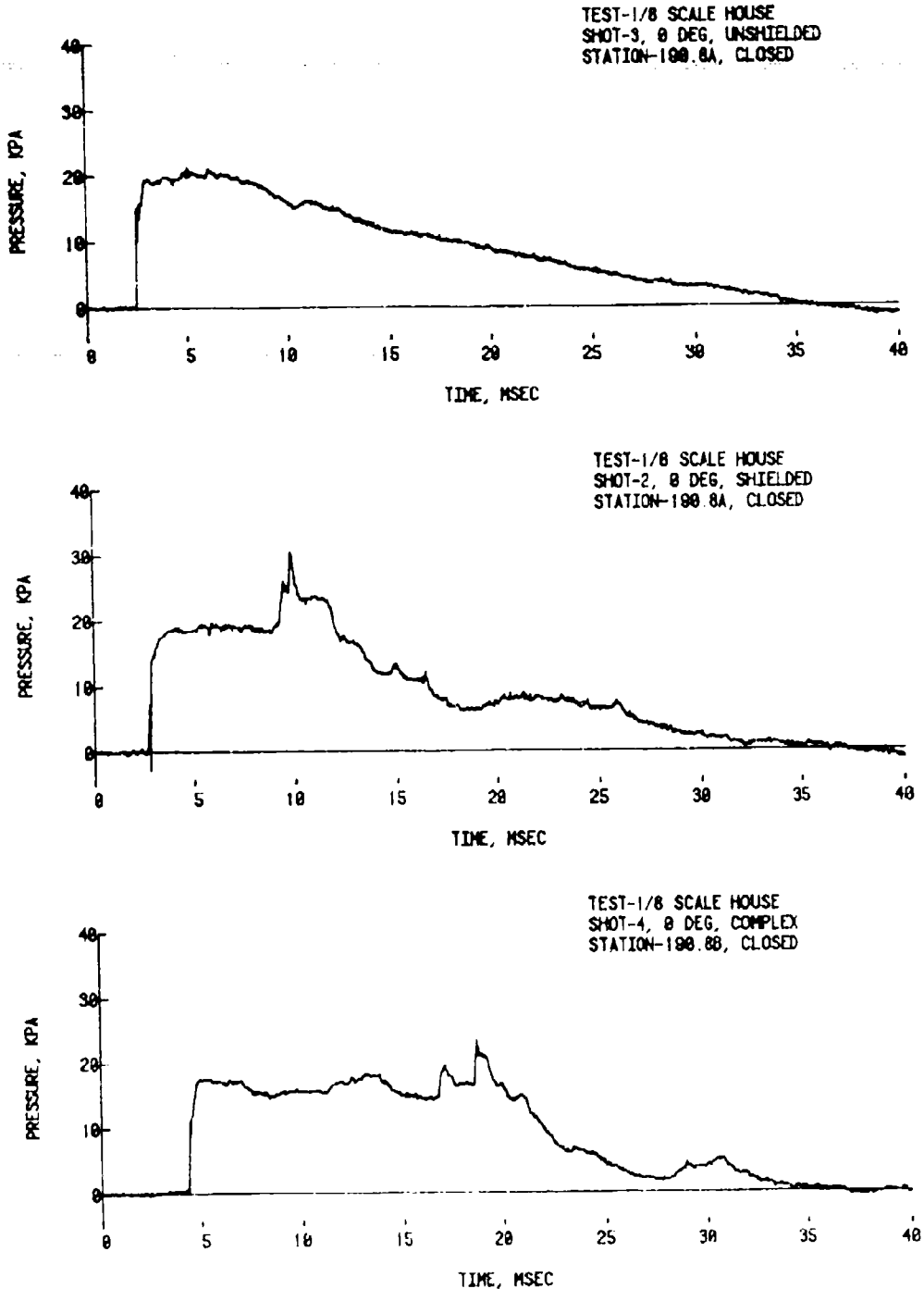
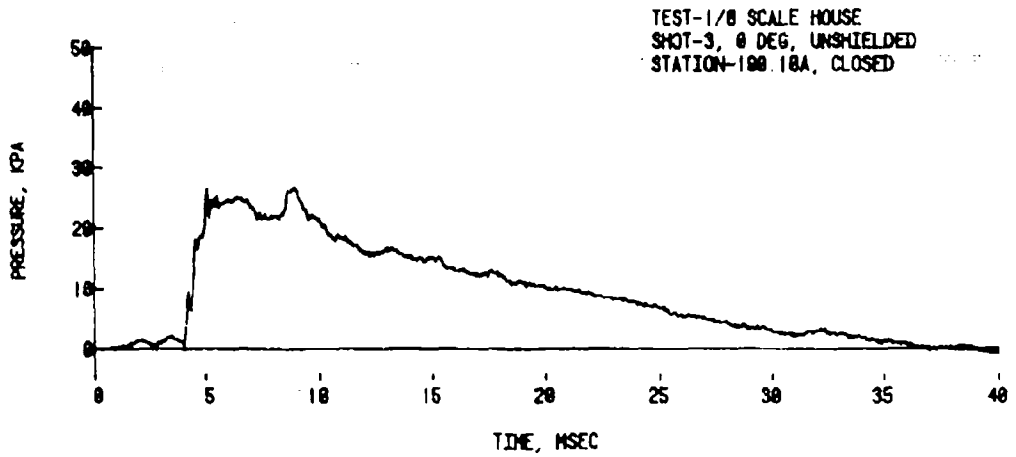
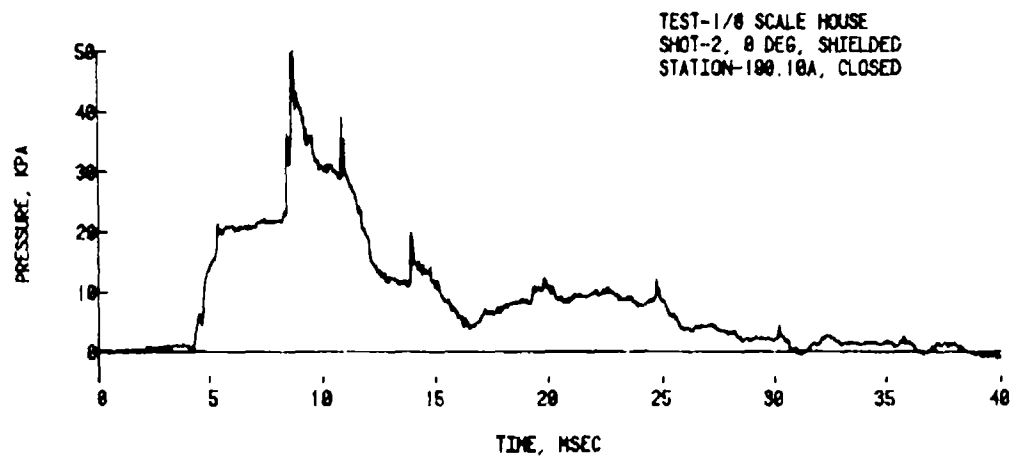


Figure 19. Comparison of rear roof loading for Shots 2, 3, and 4.





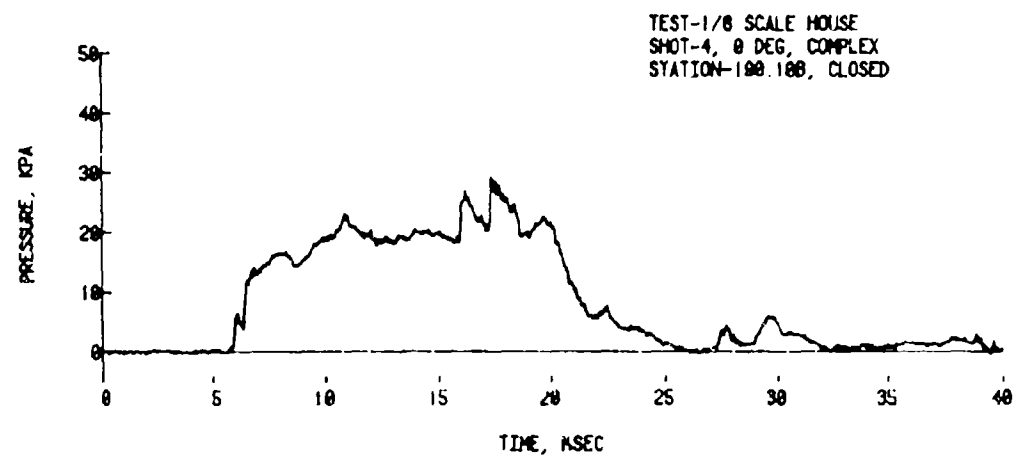


Figure 20. Comparison of rear wall loading for shots 3, 2, and 4

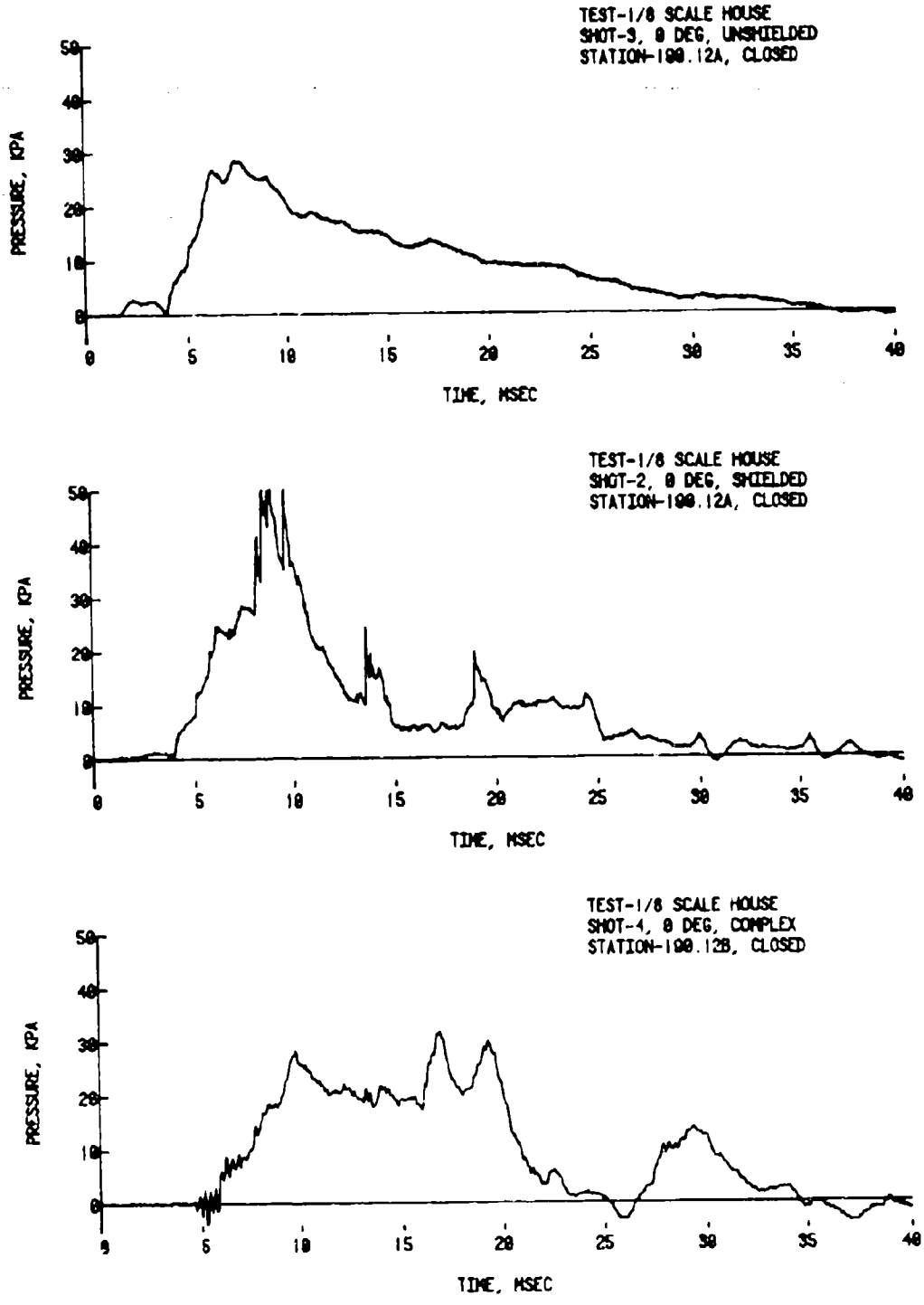


Figure 20. (Cont.) Comparison of rear wall loading for Shots 2, 3, and 4.

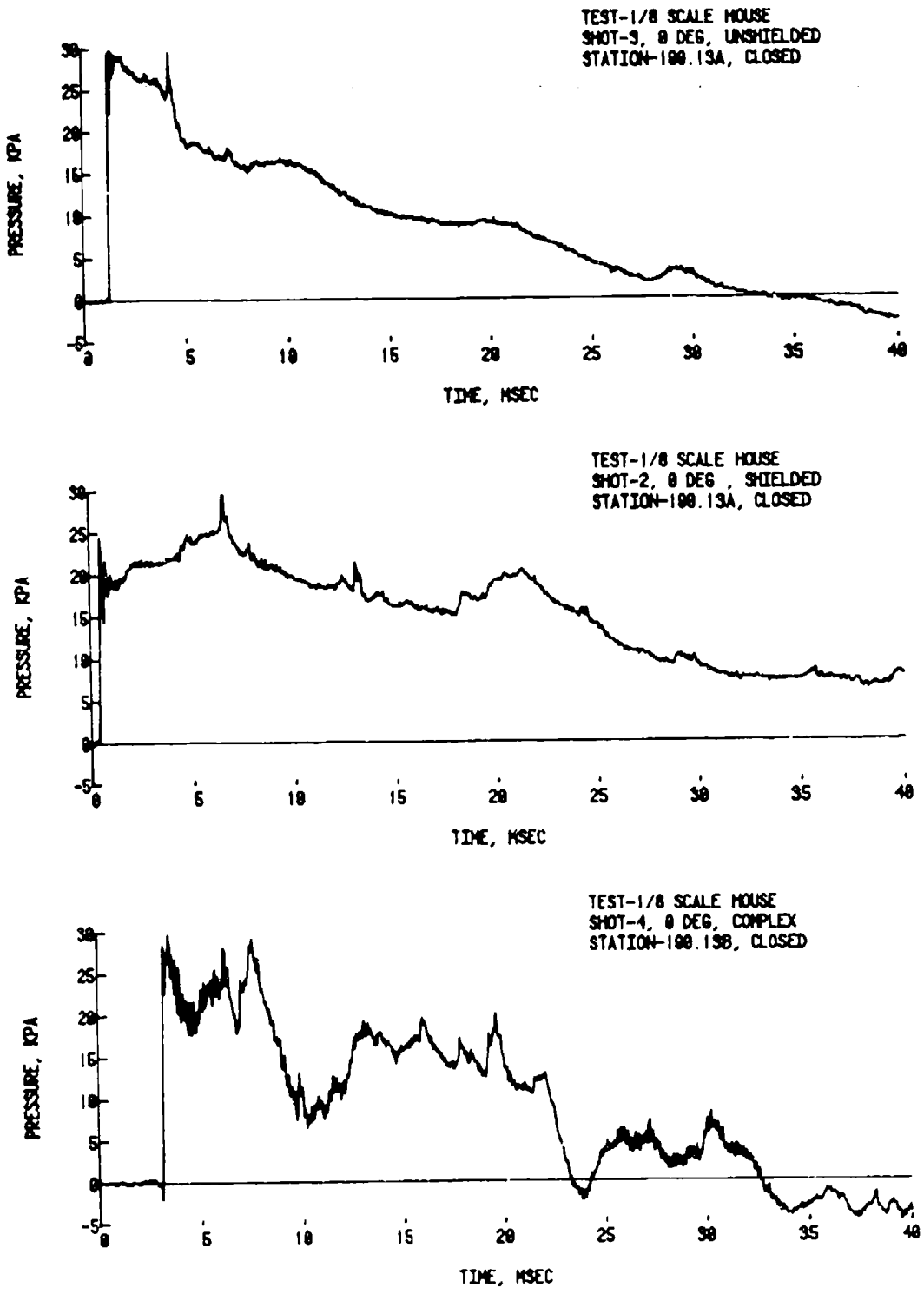


Figure 21. Comparison of loading on left side wall for Shots 3, 2, and 4.

The maximum peak loading was expected for the normal loading (0° incidence) at the front wall[3]. Equation 1 gives, for Shot 3, (the model unshielded) a normal reflected value, P_{ref}, of overpressure of 62.9 kPa for the peak free field value, P_s, of 28 kPa.

$$P_{ref} = 2P_s \left[\frac{7P_1 + 4P_s}{7P_1 + P_s} \right] , \qquad (1)$$

where P_{ref} and P_s are defined above. P_1 is the ambient atmospheric pressure on the test site at shot time. Reference 4 shows that for an angle of 40° (angle between blast wave and front roof surface), the peak reflected pressure is very nearly equal to the normal value calculated from Equation 1. Figure 17 shows that the peak initial measured pressure (about the same as calculated) at the front wall for the unshielded model is degraded as the in-line shields and the complexes are exposed to the blast. Values of about 63 kPa (Table VIII) are degraded to something below 20 kPa. The similar peak loading found on the front roof when the model was unshielded does not degrade as much. The value goes from about 61.5 kPa to a value between 40 and 50 kPa instead of less than 20 kPa.

The rear roof loading (Figure 19) shows a rounding of the pressure-time trace to values below the free-field value. Falling slopes[5] of terrain cause similar effects to those measured on the rear roof. The values of the initial peak pressures measured on the rear wall are also less than free-field values. A difference in the pressure-time records is that large reflected spikes do occur. For example, see Figure 20, Stations 190.10A and 190.12A. Table IX lists these and the other maximum values.

Figure 21 shows the comparison of the records measured on the left side wall (as seen by the blast wave). The most noticeable effect is the variety of waveform changes. The in-line shield causes some decrease in peak initial overpressure.

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3 *C. W. Lampson, "Resume of the Theory of Plane Shock and Adiabatic Waves with Applications to the Theory of the Shock Tube", Ballistic Research Laboratories Technical Note No. [illegible], March [illegible].* (AD#629328)

4 *Samuel Glasstone and Philip J. Dolan, "The Effects of Nuclear Weapons", Department of the Army Pamphlet No. 50-3, Hq., Dept. of Army, March 1977.*

5 *Kenneth Kaplan, "[illegible] and Predictions", Ballistic Research Laboratory [illegible] ARBRL-[illegible], [illegible].* (AD#A051569)

Table VIII. Comparison of Initial Peak Overpressure, kPa

Station	Location	Shot 3	Shot 2	Shot 4	Shot 5	Shot 6	Shot 7	Remarks
190.0	Free-field	28.0	26.3	28.0	27.2	27.2	--	
1	Front wall	61.4	32.4	25.1	27.6	13.0	21.7	Shot 3-unshielded
2	Front wall	63.2	14.3	12.6	22.1	20.6	9.2	
3	Front wall	57.7	24.9	27.2	47.5	30.2	21.7	Shot 2-in-line shields
4	Front wall	--	12.8	15.9	39.2	34.6	14.2	
5	Front roof	61.3	51.2	46.4	15.2	--	--	Shot 4-0° complex, model closed
5I	Attic	--	--	--	--	3.6	<1.0	
6	Front roof	60.8	50.3	51.0	30.8	31.8	52.2	Shot 5-45° complex, model closed
7	Rear roof	22.1	16.4	15.2	12.7	--	--	
7I	Ground floor	--	--	--	--	1.8	<1.0	
8	Rear roof	12.3	14.4	10.0	10.5	10.1	8.8	Shot 6 -45° complex, model open
9	Rear wall	9.4	4.6	5.6	10.5	2.9	10.0	
10	Rear wall	8.8	3.4	5.9	9.8	3.6	3.6	
11	Rear wall	8.6	5.6	--	2.5	<1.0	8.4	Shot 7-0° complex, model open
12	Rear wall	8.2	3.2	5.3	1.3	1.0	1.8	
13	Left side wall	28.8	19.3	27.0	3.4	1.0	17.8	

Table IX. Comparison of Maximum Peak Overpressure, kPa

Station	Location	Shot 3	Shot 2	Shot 4	Shot 5	Shot 6	Shot 7	Remarks
190.0	Free-field	28.0	26.3	28.0	27.2	27.2	--	
1	Front wall	61.4	40.7	39.3	45.0	44.8	32.1	Shot 3-unshielded
2	Front wall	63.2	57.4	40.5	42.1	41.8	39.3	
3	Front wall	60.0	50.1	32.5	47.5	42.2	30.0	Shot 2-in-line shields
4	Front wall	60.0	54.1	34.7	53.8	47.4	31.9	
5	Front roof	61.3	51.2	46.4	23.3	--	--	Shot 4-0° complex, model closed
5I	Attic	--	--	--	--	14.8	14.2	
6	Front roof	61.6	50.3	51.0	41.5	38.8	52.2	
7	Rear roof	23.6	30.5	22.9	26.4	--	--	Shot 5-45° complex, model closed
7I	Ground floor	--	--	--	--	25.0	25.6	
8	Rear roof	21.1	29.3	21.7	29.6	28.6	22.7	
9	Rear wall	21.7	34.3	25.1	31.5	30.0	20.9	Shot 6-45° complex, model open
10	Rear wall	26.6	46.1	28.5	37.8	38.0	25.4	
11	Rear wall	22.5	44.4	30.9	31.9	30.9	24.8	
12	Rear wall	28.6	52.1	32.0	38.9	34.6	26.0	Shot 7-0° complex, model open
13	Left side wall	29.6	29.5	28.1	47.8	39.6	27.3	

Tables X and XI summarize the values of positive overpressure impulses and arrival times for the test series. The general effect upon arrival time caused by shielding from the blast wave was to increase the arrival time over that obtained for the unshielded model. The average positive overpressure impulse was greatest on the front wall, 377 kPa-ms and 368 for the unshielded and the in-line shielded models. The front roof value was about the same, 370 kPa, for both shots. The average value decreased to 335 kPa for the front wall of the model when in the 0° complex. Within a few percent, the positive impulse at the remaining stations was not affected by the in-line shielding or the complex.

B. Blast Wave at Oblique Angle Incidence

Comparison of free-field records with records from representative stations on the unshielded model, 0° complex, and from the 45° complex will be made here. Figure 22 shows the free-field records from the several shots. There is some variation in peak pressure from shot to shot but they are quite similar except for the reflected waves from the complexes as shown at about 15 ms on Shots 5 and 6.

Figures 23 - 31 show the changes in waveforms that occur as function of model or orientation to the blast wave. Figures 23 and 24 illustrate the decay in initial peak overpressure when the front wall is shielded within the two complexes. The records from the open model were not much different from those recorded on the closed model. The arrival times increased both with the shielding and as the complex (for 45°) was changed, the stations were at greater distances as measured from the fixed free-field station.

Figure 25 shows a comparison of the loading at a front roof station. Here the waveshape change is not as great as for the front wall. Some decay in the initial peak overpressure does occur, but not as much as the decay on the front wall. The increased arrival times follow similar increases seen for the front wall.

Figure 26 shows pressure-time records from the rear roof. The complexes do cause some lowering of the initial peak pressure from approximately 20 kPa to about 15 kPa (for 45° complex). Reflections from shields at the rear part of the complex tend to increase the load on the rear roof after the first few milliseconds elapse after the blast wave passes the stations.

Figures 27 and 28 show comparisons of rear wall positions. All traces are rounded at the front with a series of waves merging to form the general profile. Again reflections appear from the rear parts of both complexes. The open model shows the most rounding at the initial shock front.

Table X. Comparison of Positive Overpressure Impulse, kPa-ms

Station	Location	Shot 3	Shot 2	Shot 4	Shot 5	Shot 6	Shot 7	Remarks
190.0	Free-field	331	334	358	337	342	---	
1	Front wall	380	---	351	339	339	376	Shot 3-unshielded
2	Front wall	370	364	346	349	336	345	
3	Front wall	380	379	339	317	308	338	Shot 2-in-line shields
4	Front wall	382	349	303	332	340	317	
5	Front roof	375	361	376	202	---	---	Shot 4-0° complex, model closed
5I	Attic	---	---	---	---	---	288	
6	Front roof	365	376	351	336	354	380	
7	Rear roof	346	340	309	323	---	---	Shot 5-45° complex, model closed
7I	Ground floor	---	---	---	---	297	314	
8	Rear roof	328	336	328	319	328	324	Shot 6-45° complex, model open
9	Rear wall	326	311	315	323	326	298	
10	Rear wall	359	345	326	332	341	324	Shot 7 -0° complex, model open
11	Rear wall	308	330	312	324	333	295	
12	Rear wall	348	356	351	323	309	322	
13	Left side wall	345	---	351	329	339	335	

Table XI. Comparison of Arrival Times, ms

Station	Location	Shot 3	Shot 2	Shot 4	Shot 5	Shot 6	Shot 7	Remarks
190.0	Free-field	0.00	0.00	0.00	0.00	0.00	0.00	
1	Front wall	0.00	0.35	0.55	2.00	2.10	0.60	Shot 3-unshielded
2	Front wall	0.00	0.35	0.90	5.10	1.45	1.00	
3	Front wall	0.00	0.35	0.55	2.70	2.75	0.60	Shot 2-in-line shields
4	Front wall	0.00	0.55	0.90	2.00	2.00	0.95	
5	Front roof	0.10	0.35	0.80	1.50	----	----	Shot 4-0° complex, model closed
5I	Attic	----	----	----	----	2.00	2.50	
6	Front roof	0.50	0.85	1.15	1.65	1.75	1.25	
7	Rear roof	3.15	3.10	5.05	3.15	----	----	Shot 5-45° complex, model closed
7I	Ground floor	----	----	----	----	2.60	2.95	
8	Rear roof	2.55	2.35	4.45	2.85	3.05	3.20	Shot 6-0° complex, model open
9	Rear wall	3.05	3.10	4.90	4.35	4.00	3.65	
10	Rear wall	4.05	4.60	5.95	3.55	3.40	4.05	
11	Rear wall	3.05	3.10	4.90	4.60	4.20	3.65	
12	Rear wall	4.10	4.35	5.95	3.55	3.50	4.05	Shot 7-45° complex, model open
13	Left side wall	1.25	1.35	3.15	3.80	3.85	1.95	

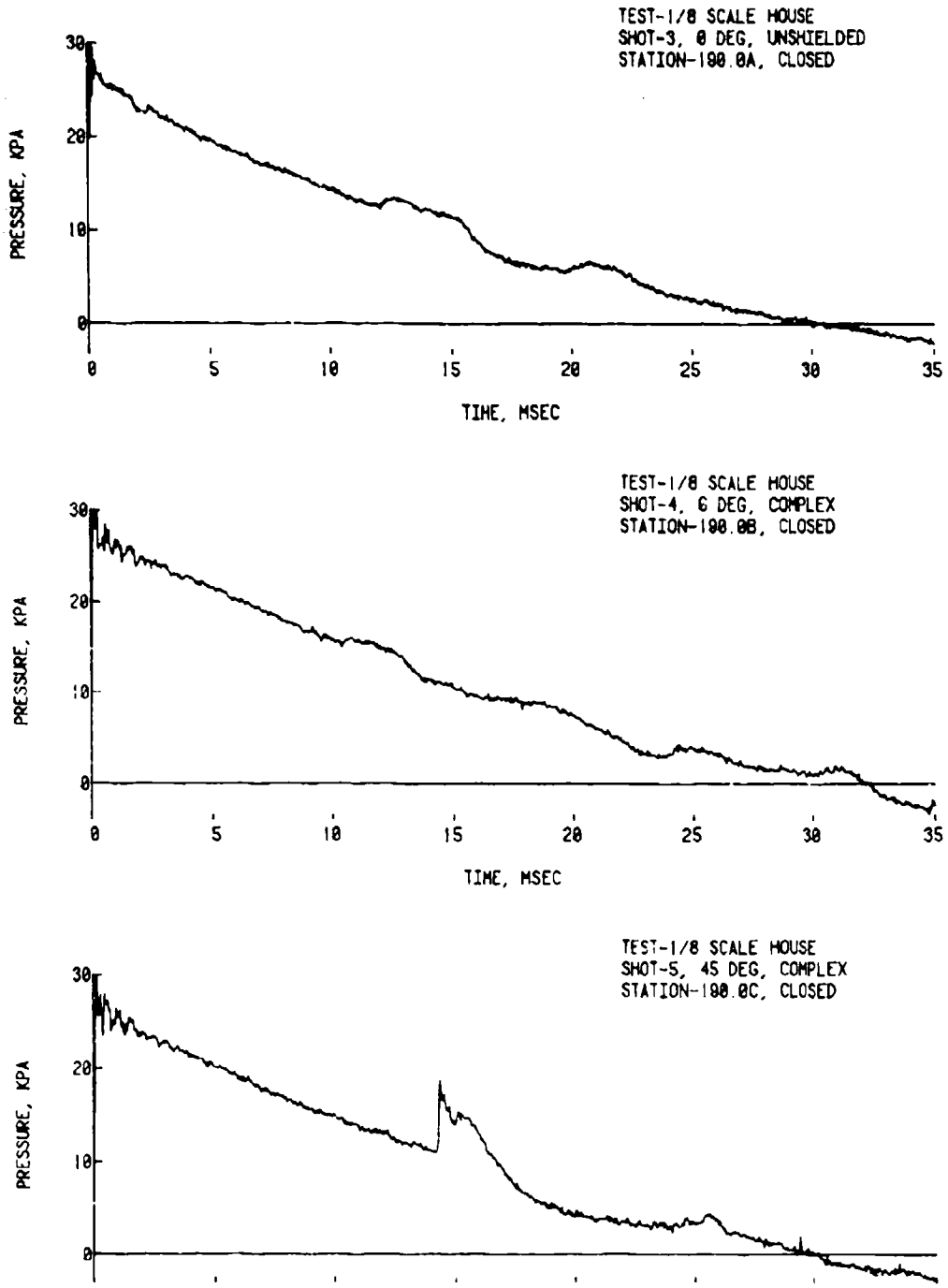


Figure 22. Comparison of free-field records.

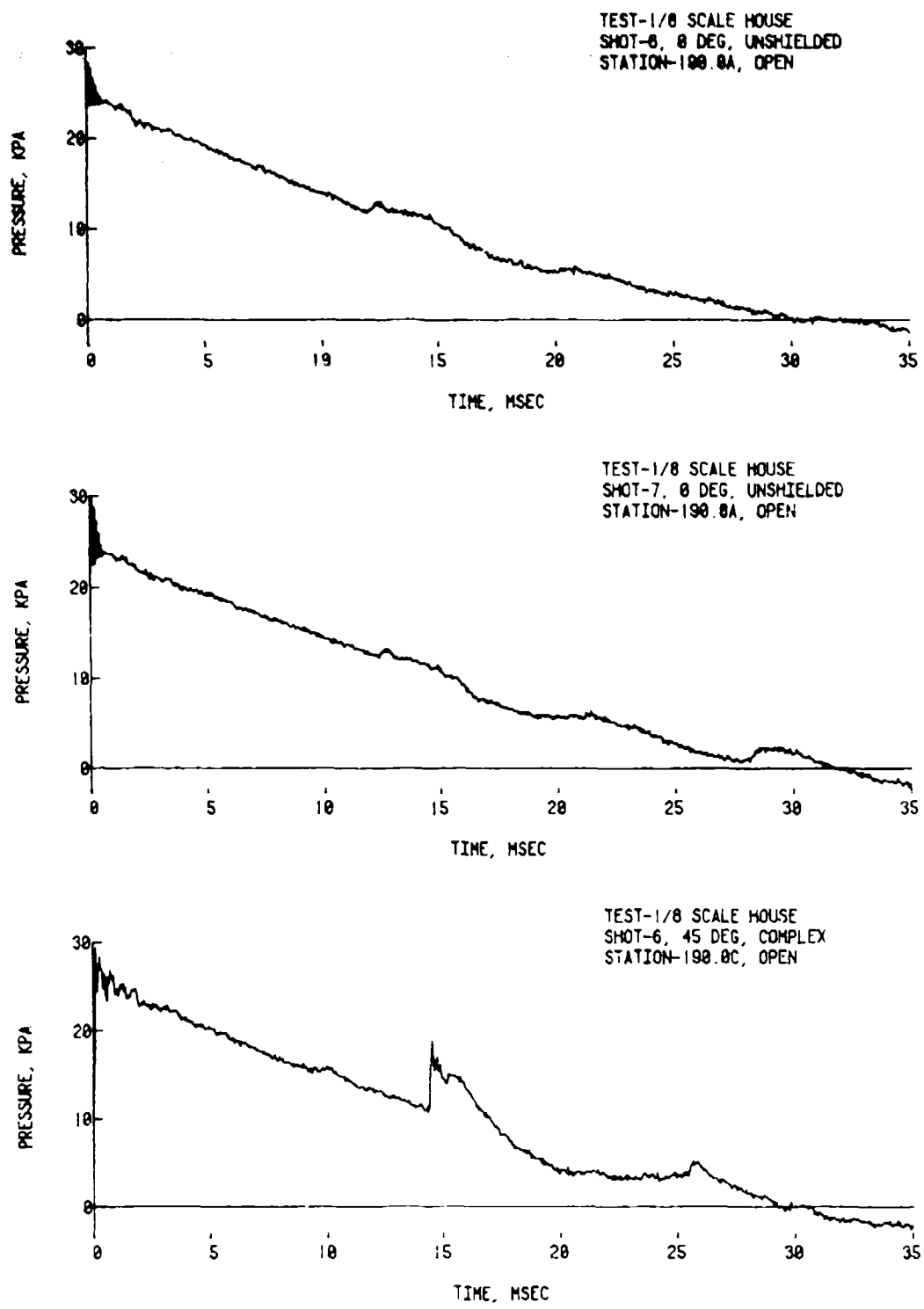


Figure 22. (Cont.) Comparison of free-field records.

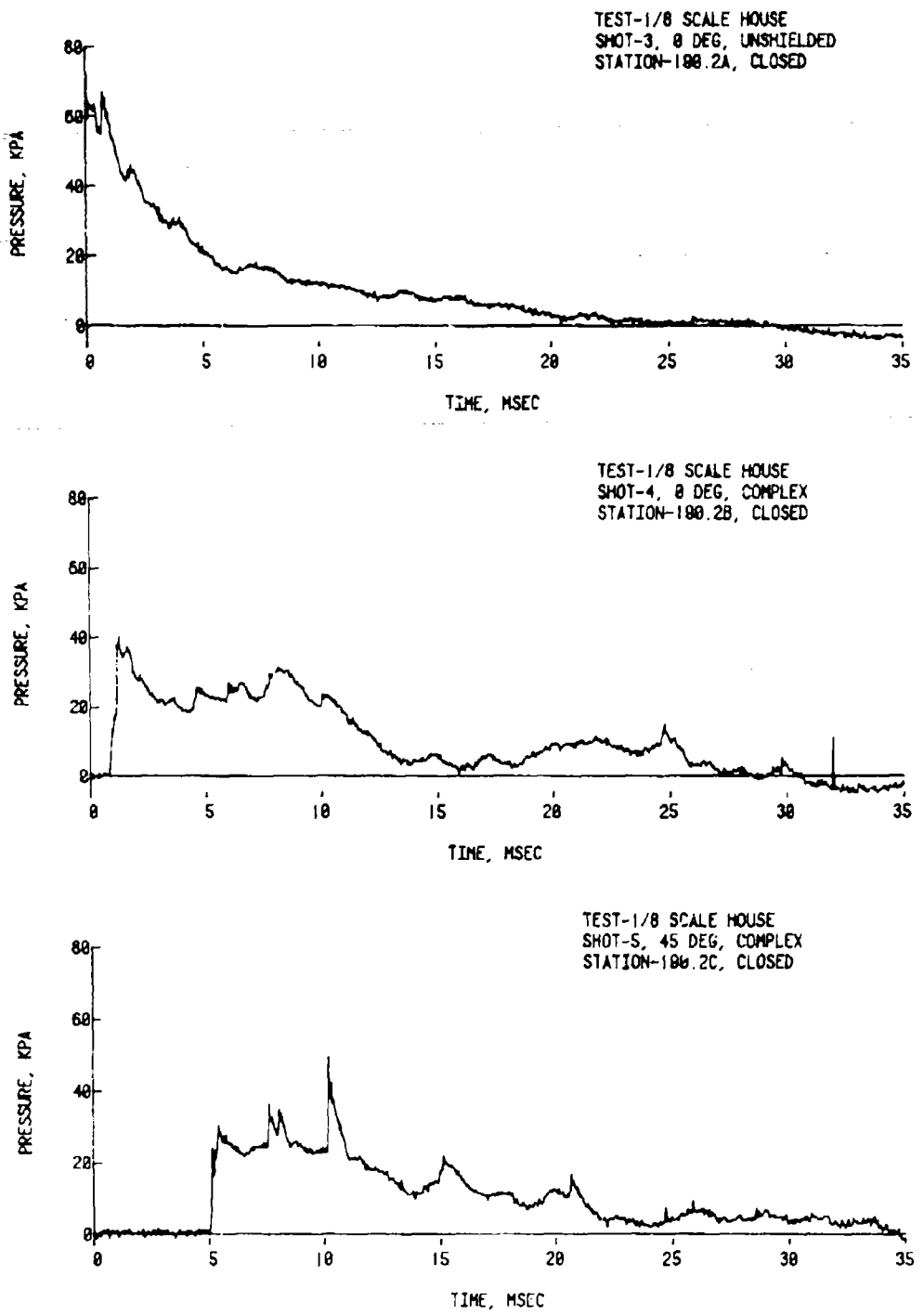


Figure 23. Comparison of loading recorded on front wall - Stations 190.2A, 190.2B, and 190.2C.

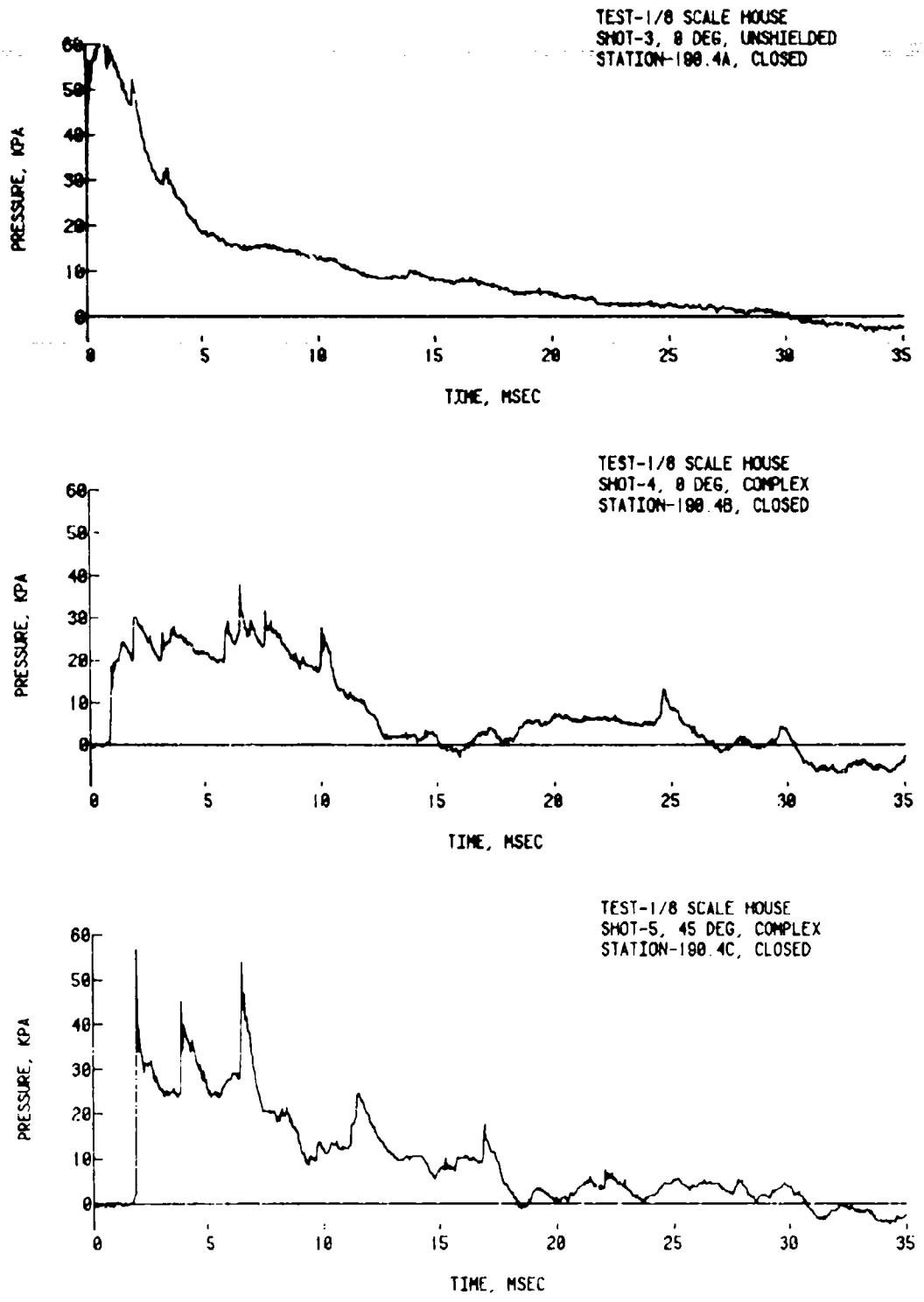


Figure 23. Comparison of loading recorded on front wall - Stations 100.4A, 100.4B, and 100.4C.

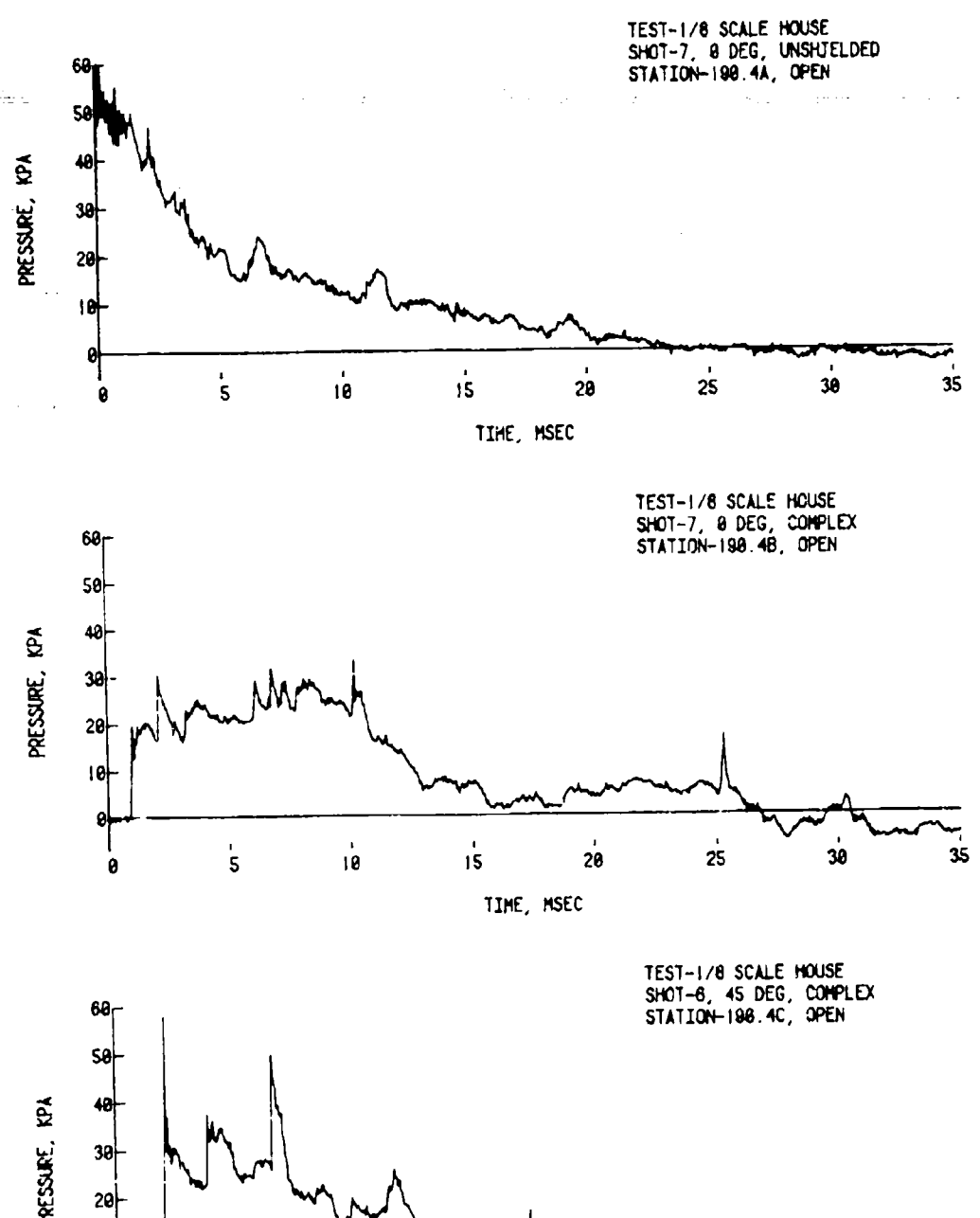


Figure 21. (Cont.) Comparison of loading recorded on front wall - Stations 190.4A, 190.4B, and 190.4C.

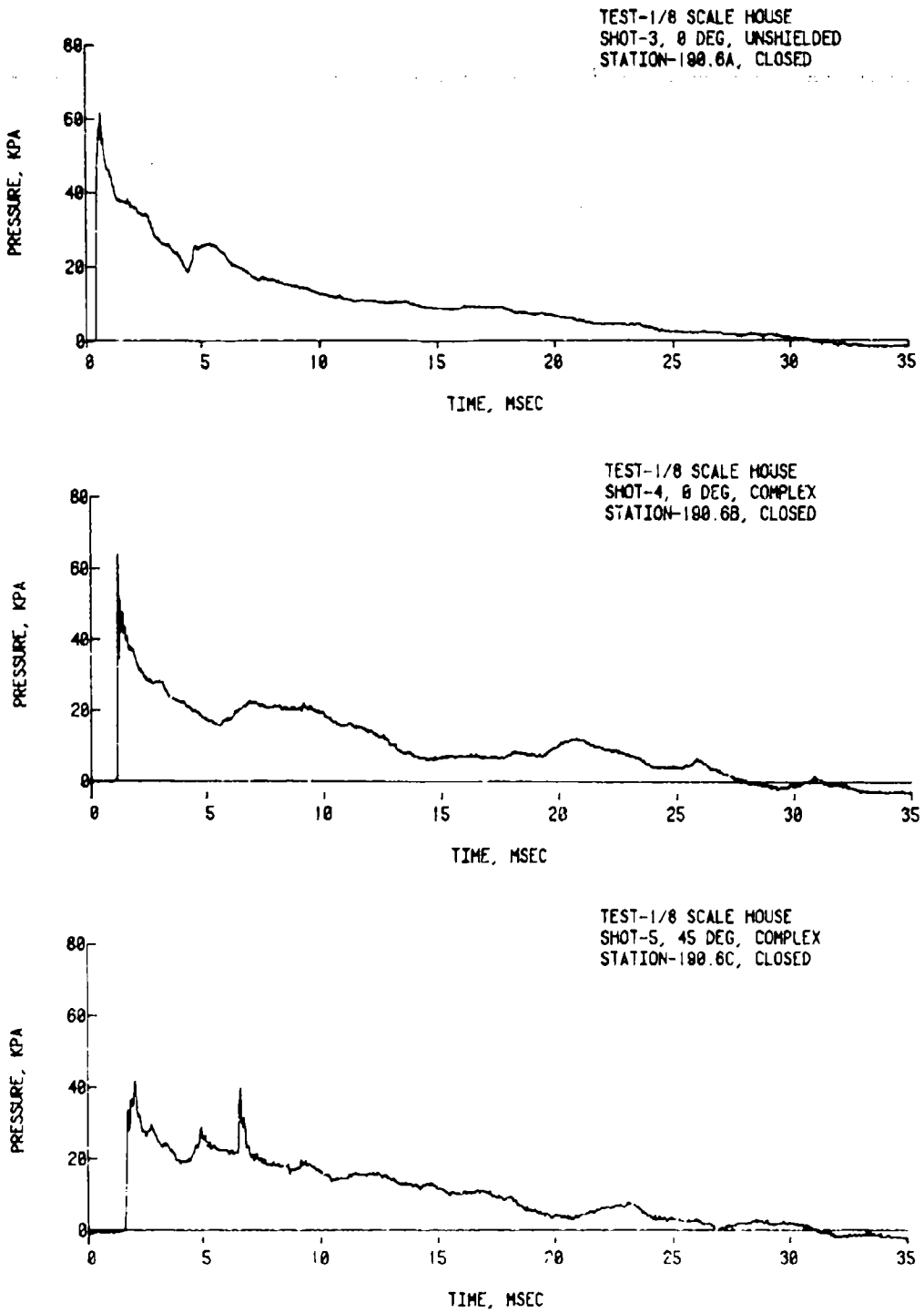


Figure 25. Comparison of loading recorded on front roof - Stations 190.6A, 190.6B, and 190.6C.

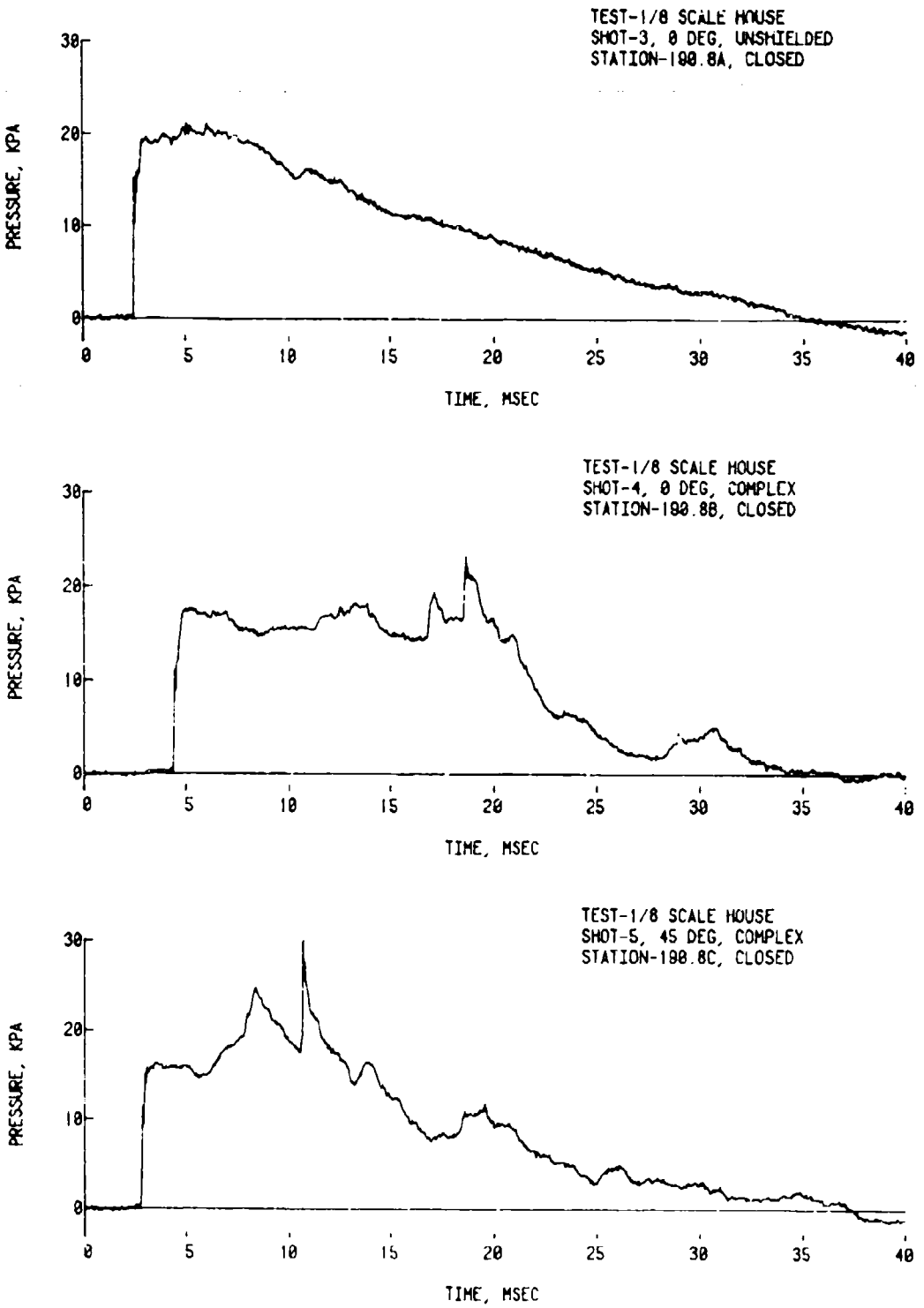


Figure 26. Comparison of loading recorded on rear roof - Stations 190.8A, 190.8B, and 190.8C.

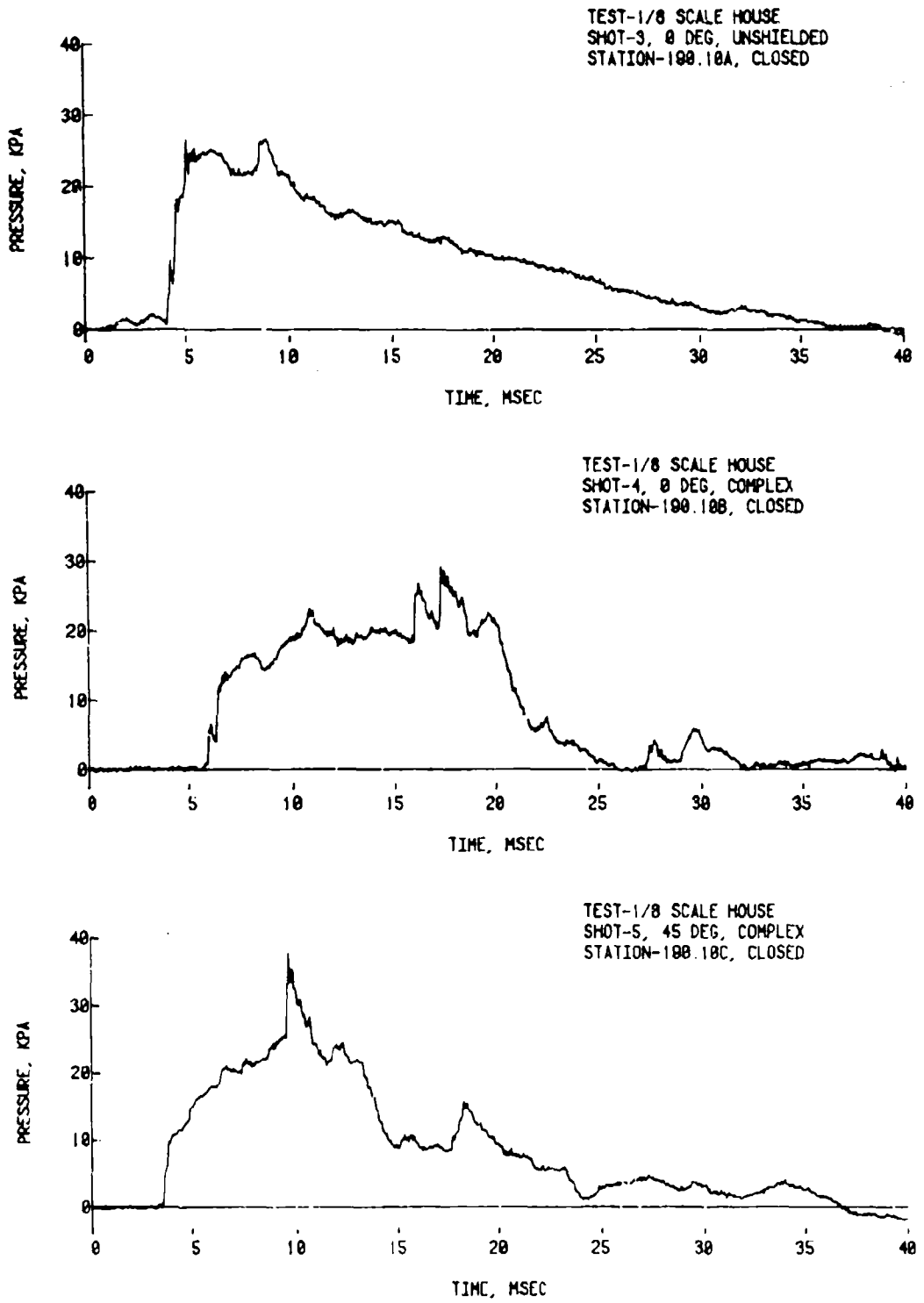
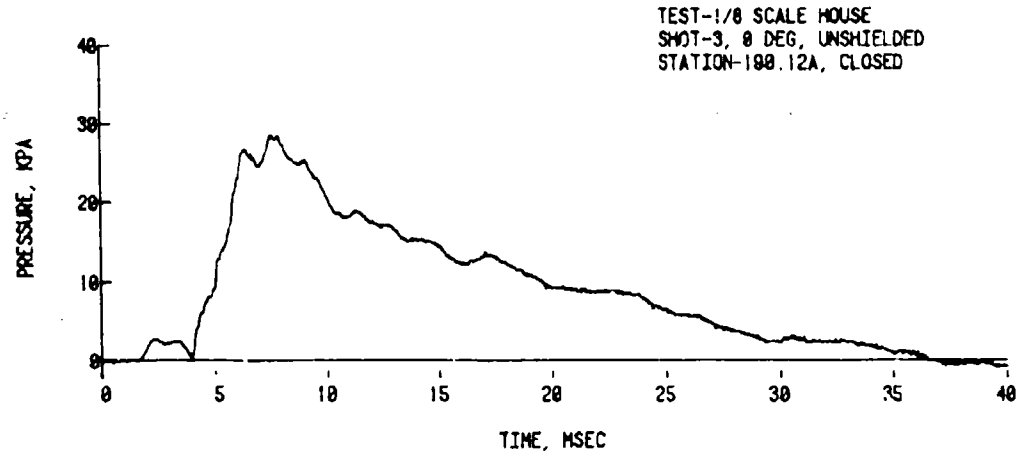
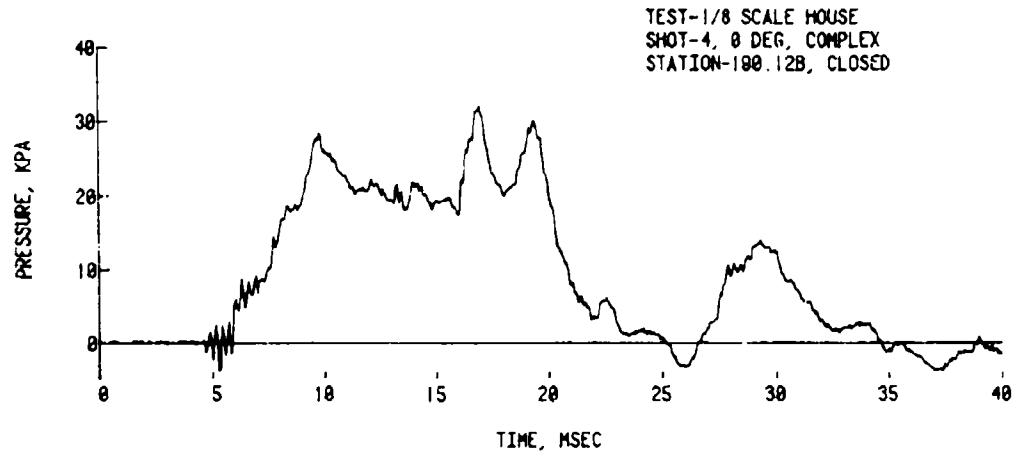


Figure 27. Comparison of loading recorded on rear wall - stations 190.10A, 190.10B, and 190.10C.





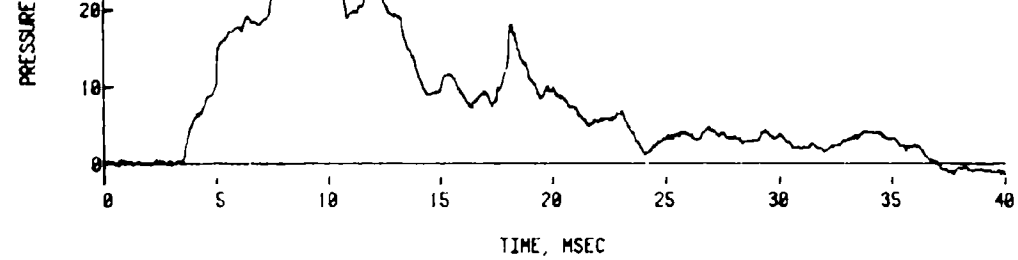
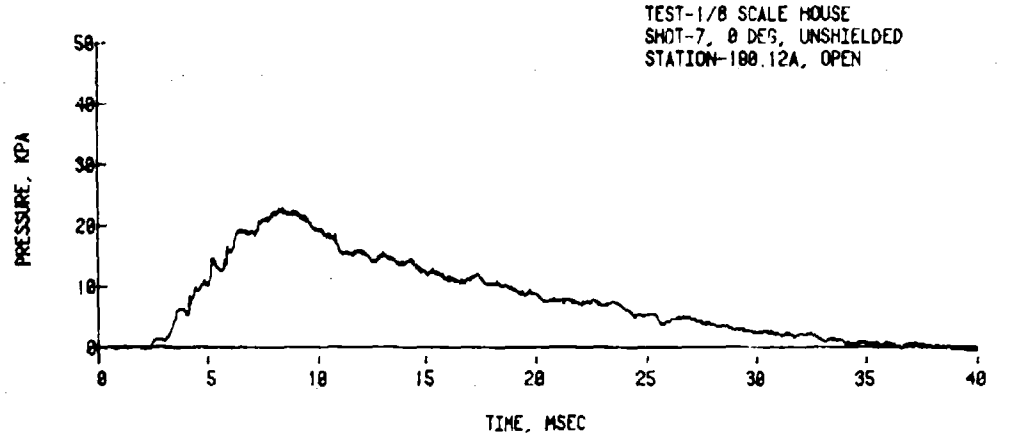
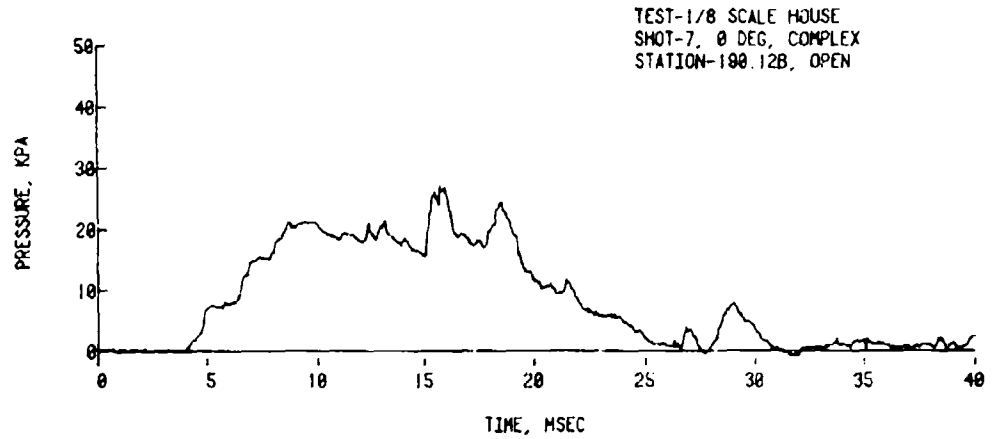


Figure 28. Comparison of loading recorded on rear wall - Stations 190.12A, 190.12B, and 190.12C.





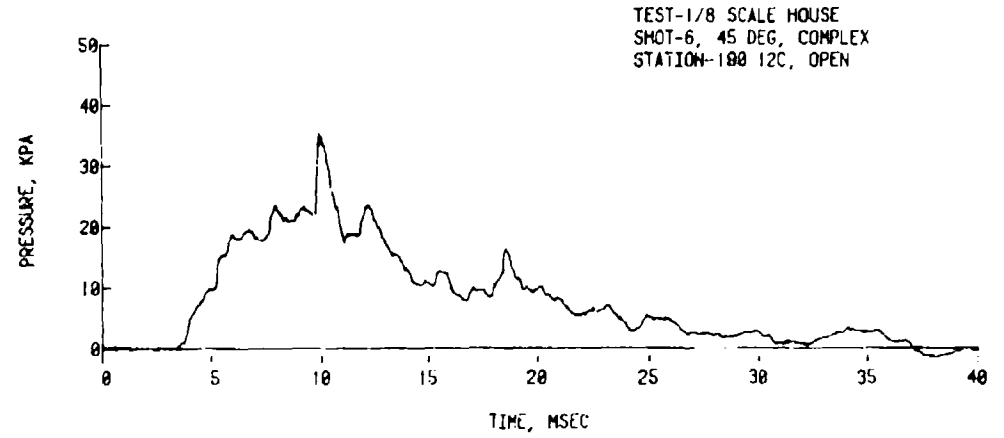


Figure 28. (Cont) Comparison of loading recorded on test wall Stations 100.12A, 100.12B, and 100.12C.

Figure 29 shows the comparison among the records made from the left side wall station. The unshielded record is very much like the free-field records. The initial peak pressure does not change very much for the 0° complex shot but does decay below the free-field value when the complex is at 45°. Additional short duration reflected pressure spikes appear on the records. The arrival time for the blast wave also increases as the shielding and orientation both delay the arrival at the left end wall station.

Figures 30 and 31 show records taken inside the open models at the attic and ground floor stations. Both of the volumes fill proportionally to the volume to area ratio[6] (V/A). The attic has a larger ratio, 12.94 m, than does the main room, 2.619 m. Accordingly, the attic fills much slower than the ground floor room. A maximum in pressure is reached somewhere between 5 - 10 ms for the ground floor room. For the attic station, the maximum pressure at this time is less than 15 kPa as compared to 25 kPa for the ground floor.

V. SUMMARY AND CONCLUSIONS

As a part of a collateral damage program sponsored by DNA at the BRL, a 1/8th scale model house complex was exposed on the Mighty Mach I and II series at the Canadian DRES test site. The models were instrumented with pressure transducers on the external walls, roof, and at points inside the models, where open models were exposed to the blast. Generally all instrumentation performed adequately to record the blast loading.

Three test configurations were exposed to the blast (25 kPa) from the high explosive charges: (1) in-line shields, (2) 0° complex, and (3) 45° complex. The last two configurations were repeated with open windows and a door in each of the two instrumented models. The pressure-time records obtained were compared to the results for the single unshielded model. Tables of pertinent parameters were given for measurements for each of the configurations tested. Pressure-time loading histories are given in the Appendixes to this report.

An analysis of the pressure-time records led to the following general conclusions:

(1) The front wall model loading was less when shielded in the complexes than when the model was unshielded.

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6 George A. Coulter, "Blast Loading in Existing Structures - Basement Models", Ballistic Research Laboratories Memorandum Report No. [illegible], August 1972 (AD# 751764).

(2) The rear wall of the model was loaded additionally with reflections from the back row of shields when in either of the complexes.

(3) The roof of the model did not experience very different loading from one configuration to the next.

(4) The left side wall loading changed with the configuration tested. It went from something resembling free field loading for the unshielded model to something that was very similar to the rear wall loading when the model was shielded in the 45° complex.

(5) Whether the model had openings or not, caused only minor adjustments to the exterior loading.

It is recommended that existing structural codes utilizing blast loading data, such as this report lists, be modified to account for the observed shielding effects. Town or city structures within such a complex as tested would tend to become less susceptible to possible collateral damage when exposed to blast from a tactical nuclear weapon.

ACKNOWLEDGEMENTS

The author wishes to thank the field staff of The Defence Research Establishment of Suffield, Alberta, Canada for their able support in the accomplishment of this test series. He wishes also to thank Messrs. H. Pearce, B. Pettit (GE-TEMPO), and V. King (BRL-TSD) for their instrumentation-calibration assistance with the test models.

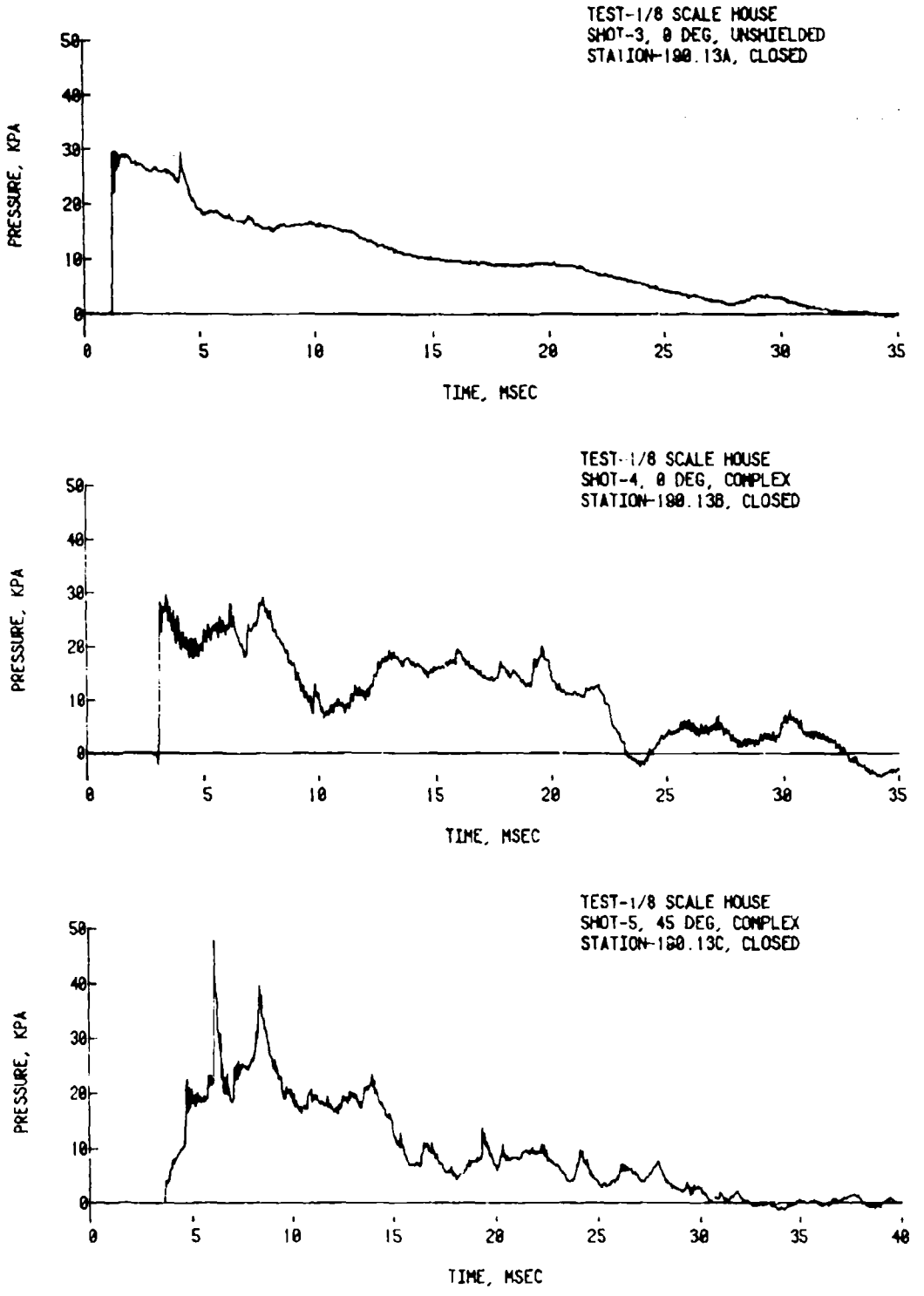


Figure 29. Comparison of loading recorded on left side wall - Stations 190.13A, 190.13B, and 190.13C.

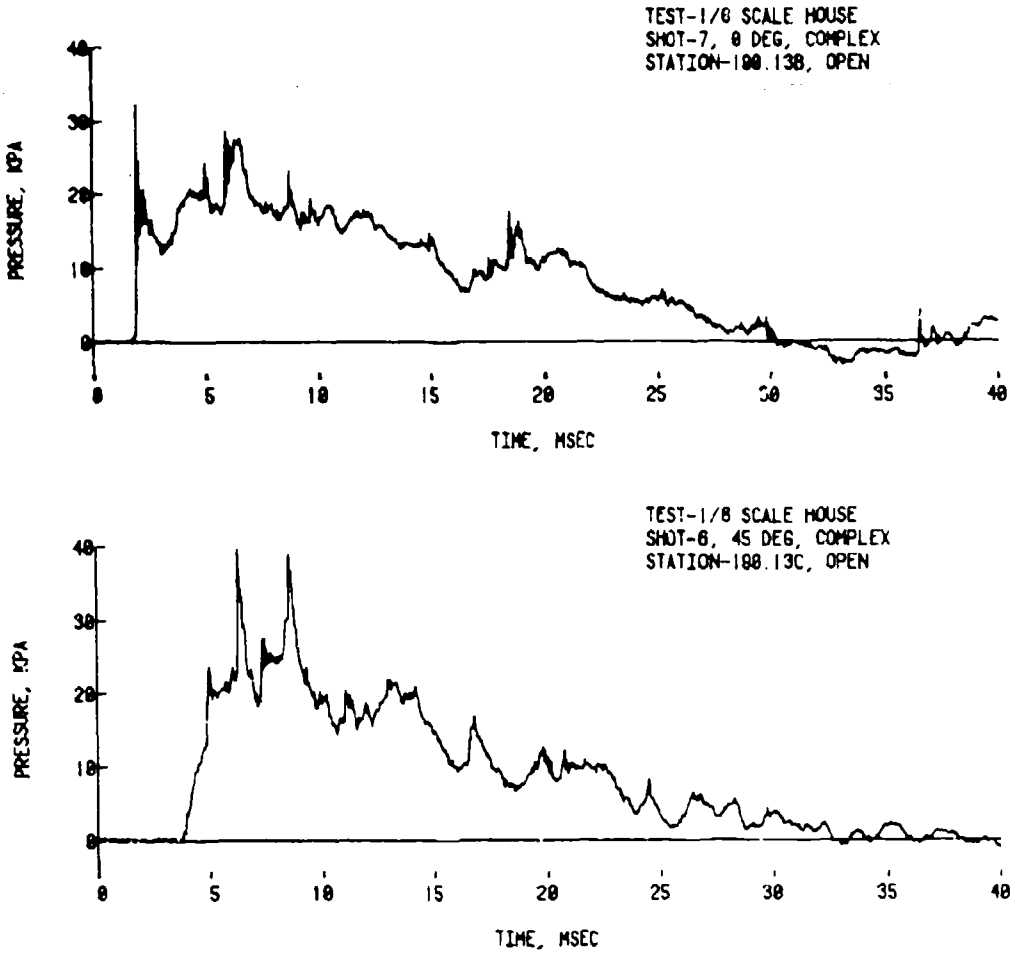


Figure 29. (Cont) Comparison of loading recorded on left side wall - Stations 100.13A, 100.13B, and 100.13C.

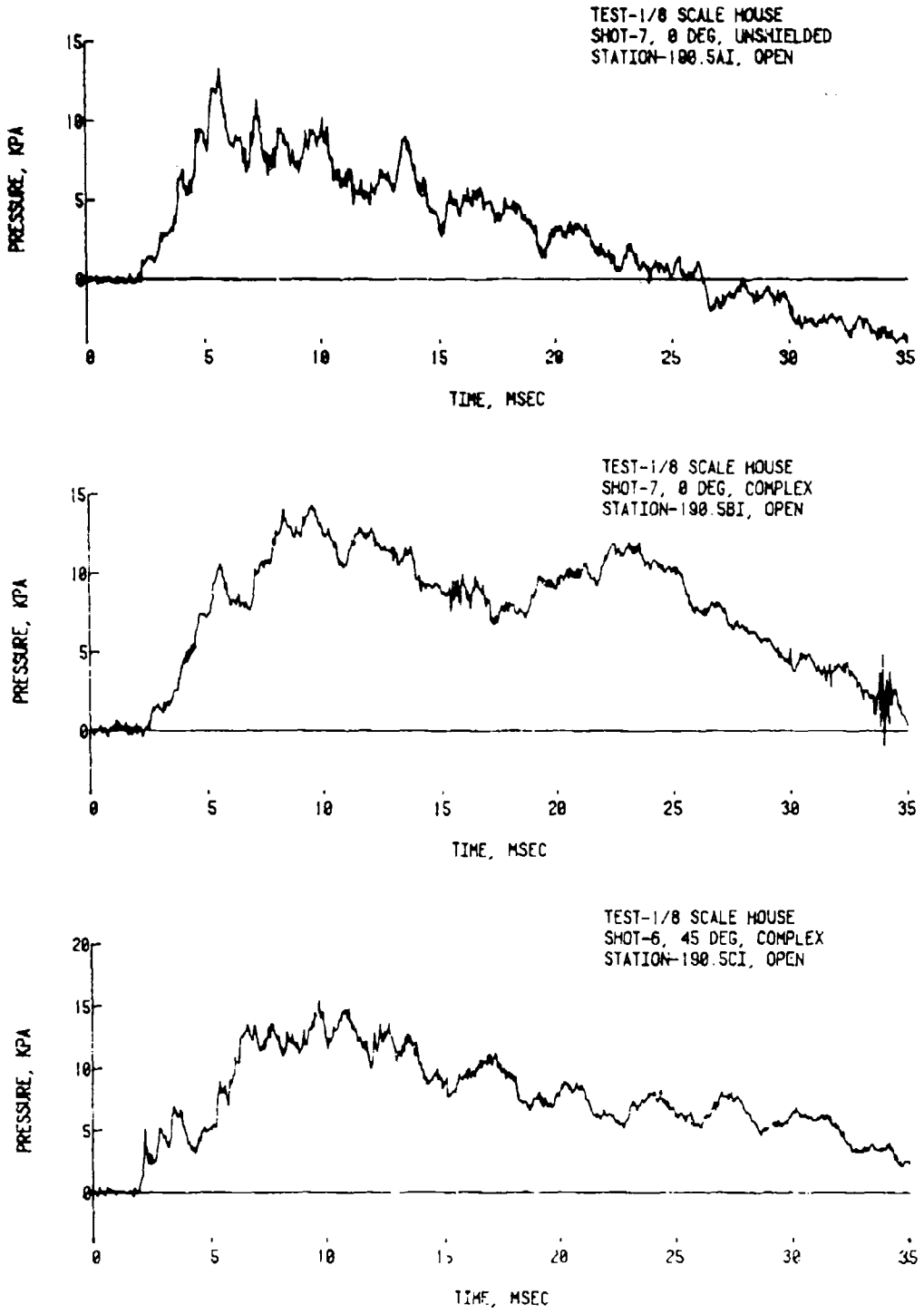


Figure 50. Comparison of loading recorded inside attic - Stations 190.5AI, 190.5BI, and 190.5CI.

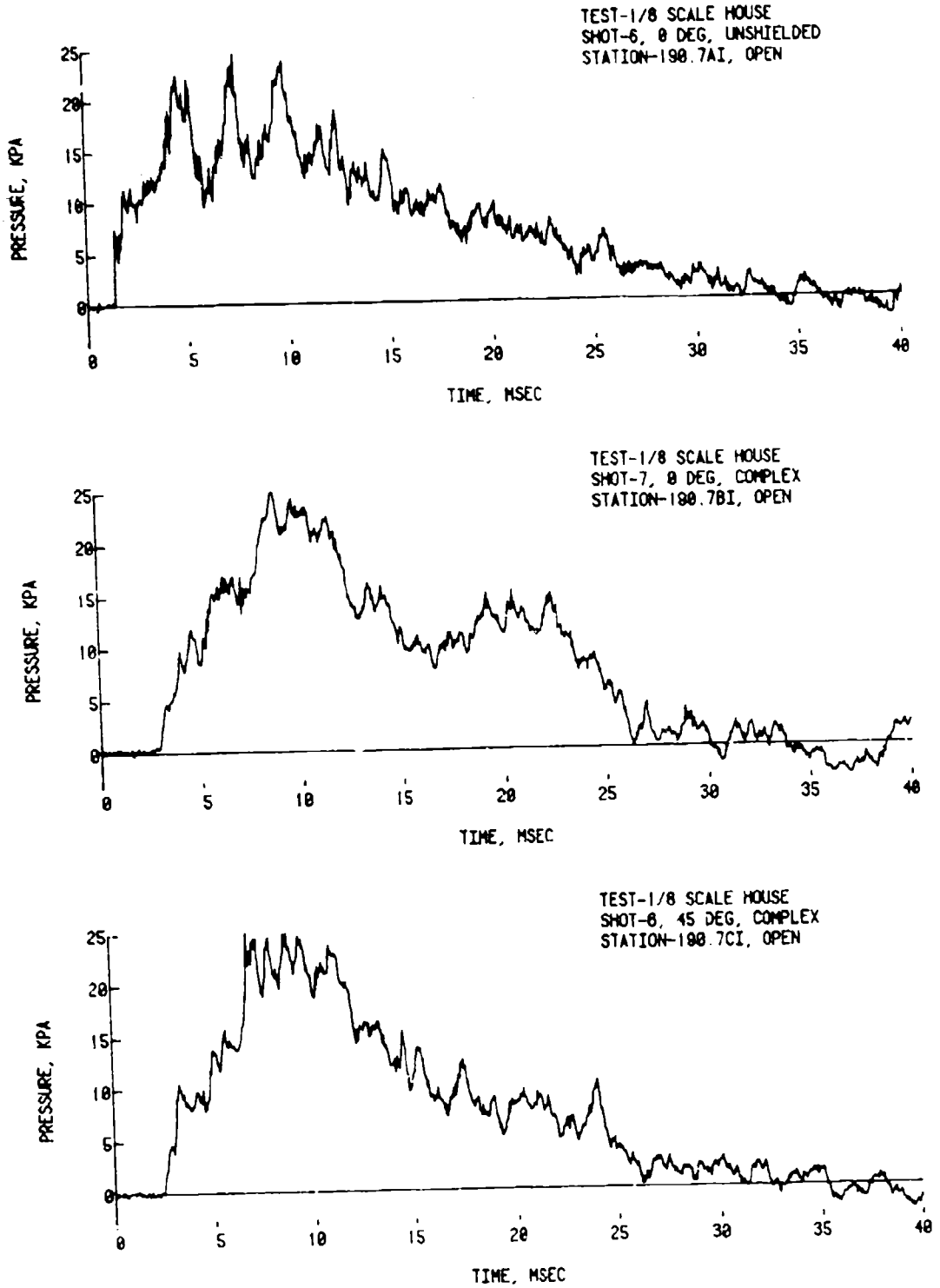
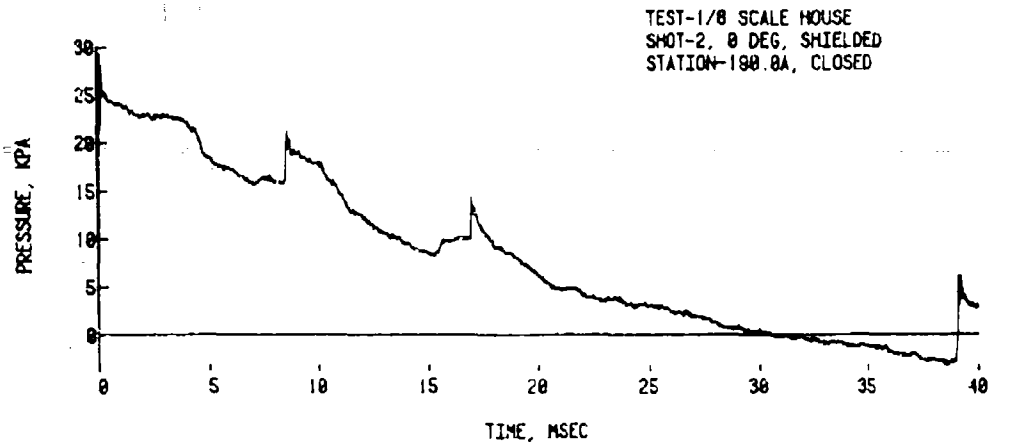
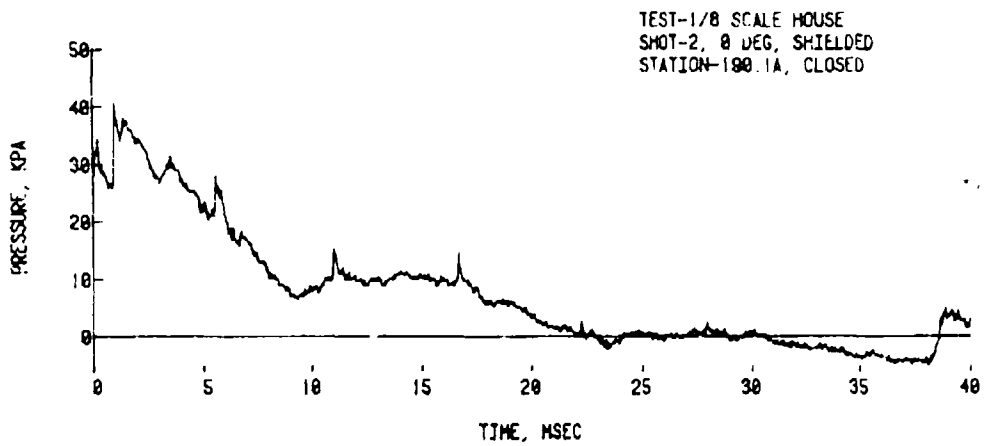


Figure 51. Comparison of loading recorded on ground floor - Stations 190.7AI, 190.7BI, and 190.7CI.

APPENDIX A

Pressure-Time Histories, Shot 2





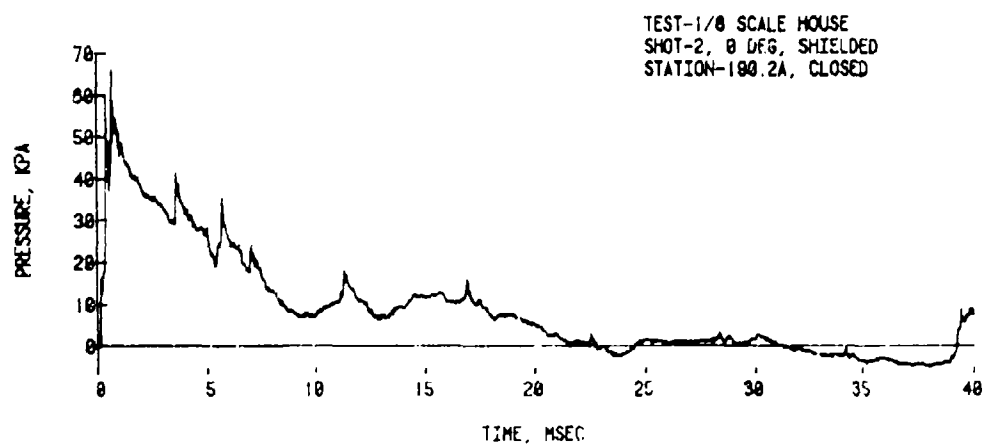
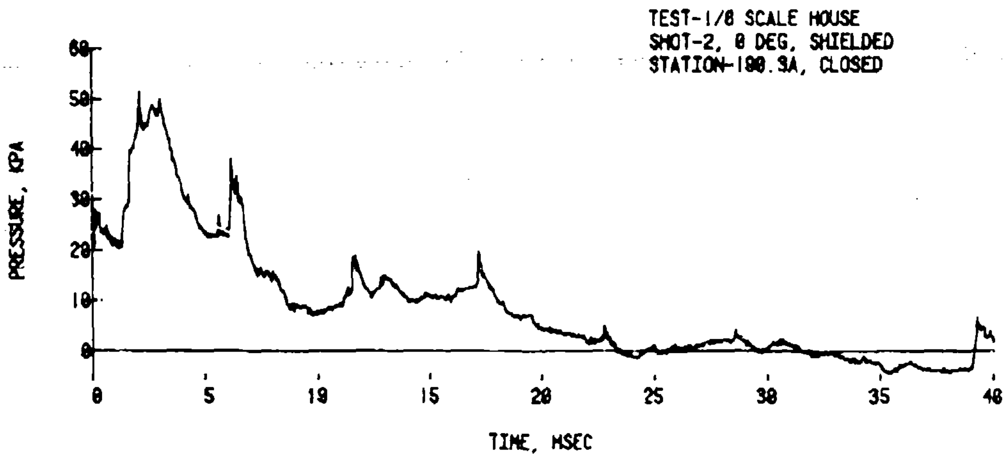
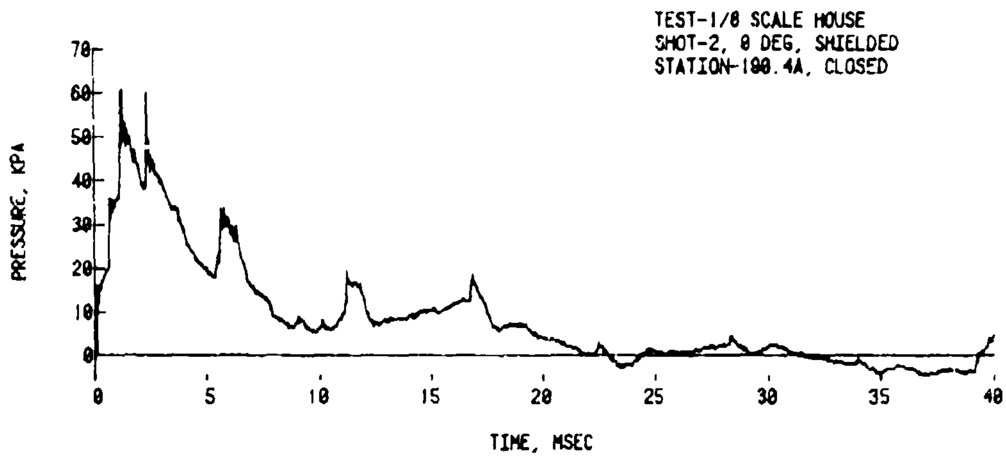


Figure A-1. Records from shielded model house, 0 degrees, Stations 198.0A, 198.1A, and 198.2A, Shot 2.





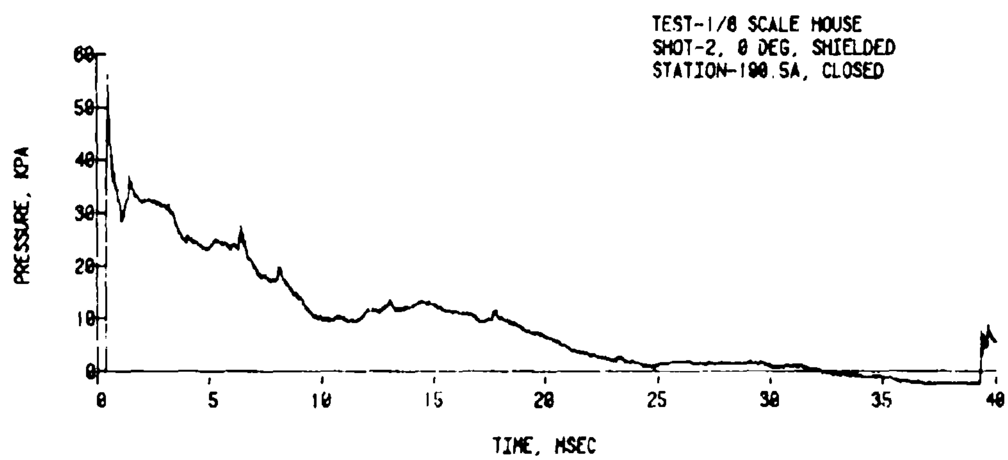


Figure A.[illegible] Records from shielded model house, 0 degrees, stations 190.3A, 190.4A, and 190.5A, Shot 2

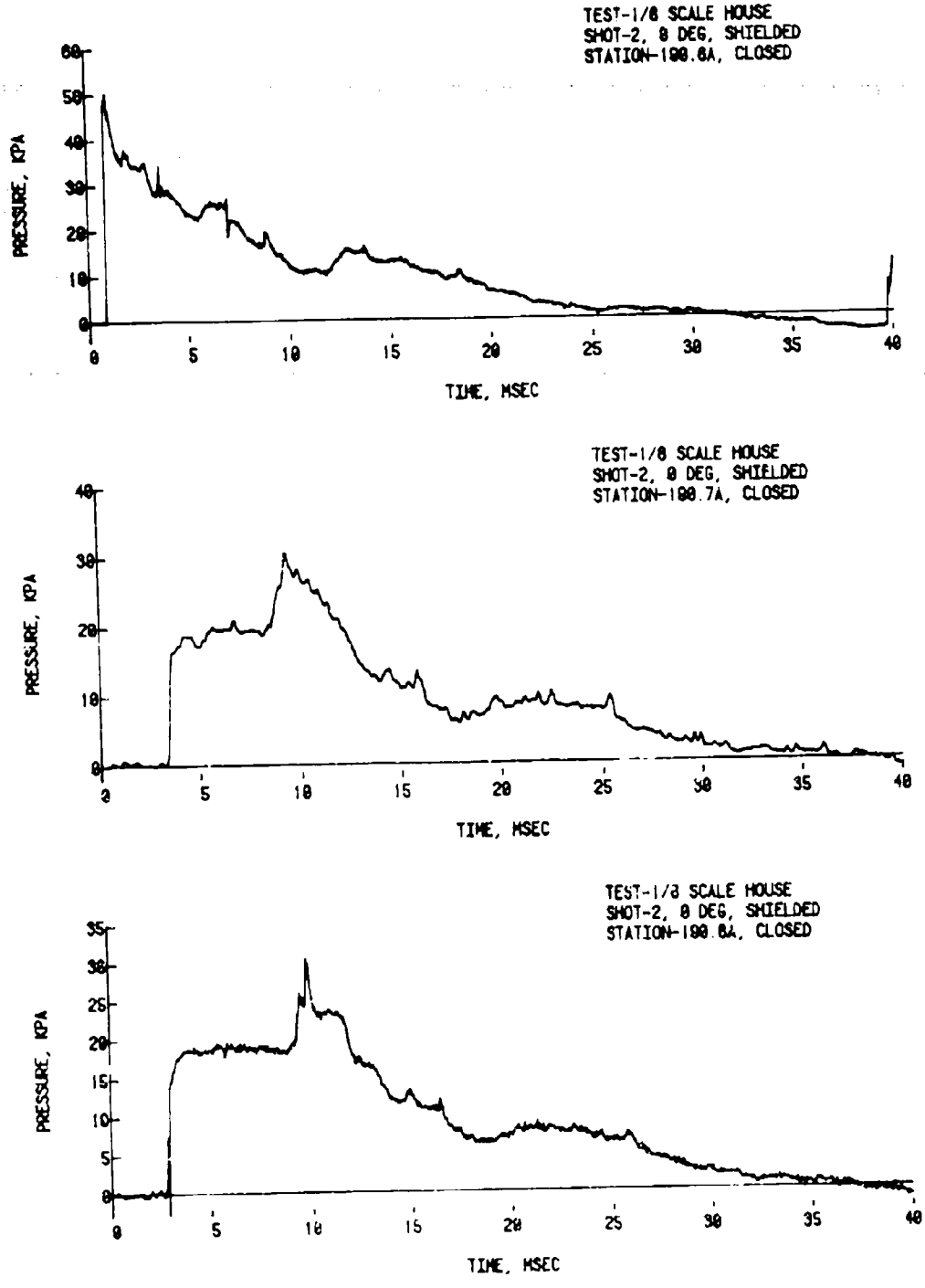
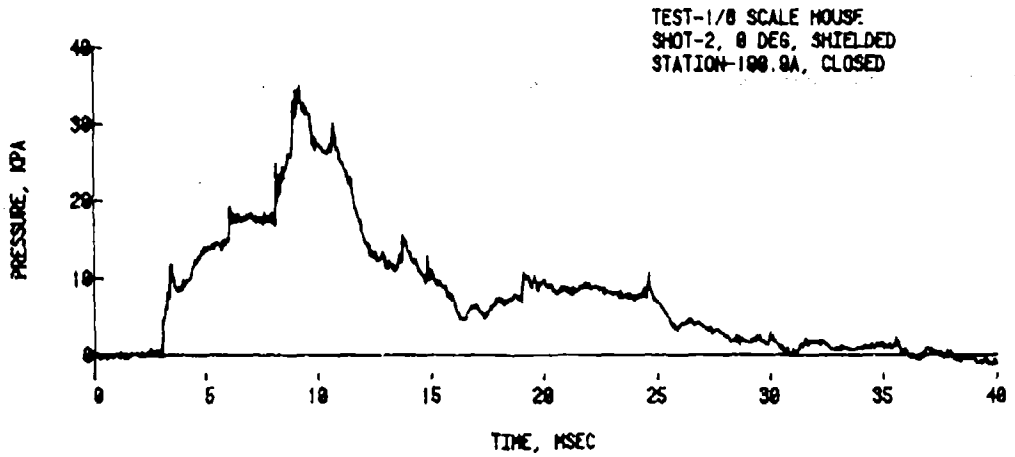
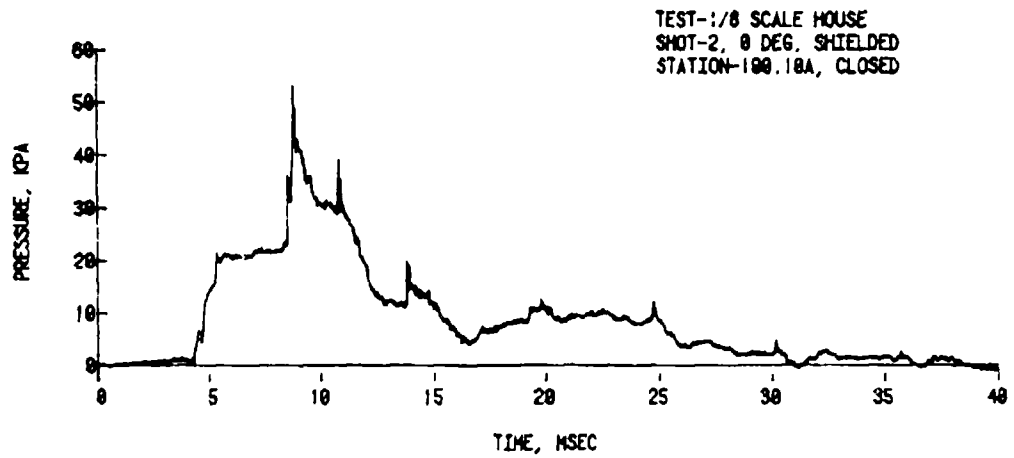


Figure A-5. Records from shielded model house, 0 degrees, Station 190.6A, 190.7A, and 190.6A, Shot 2.





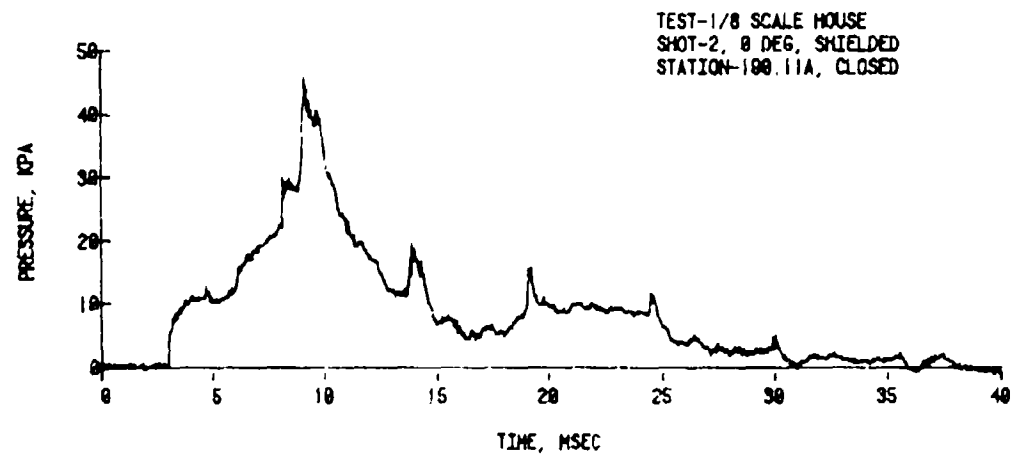


Figure A-1. Records from shielded model house, 0 degrees, station 100.9A, 100.10A, and 100.11A, Shot 2.

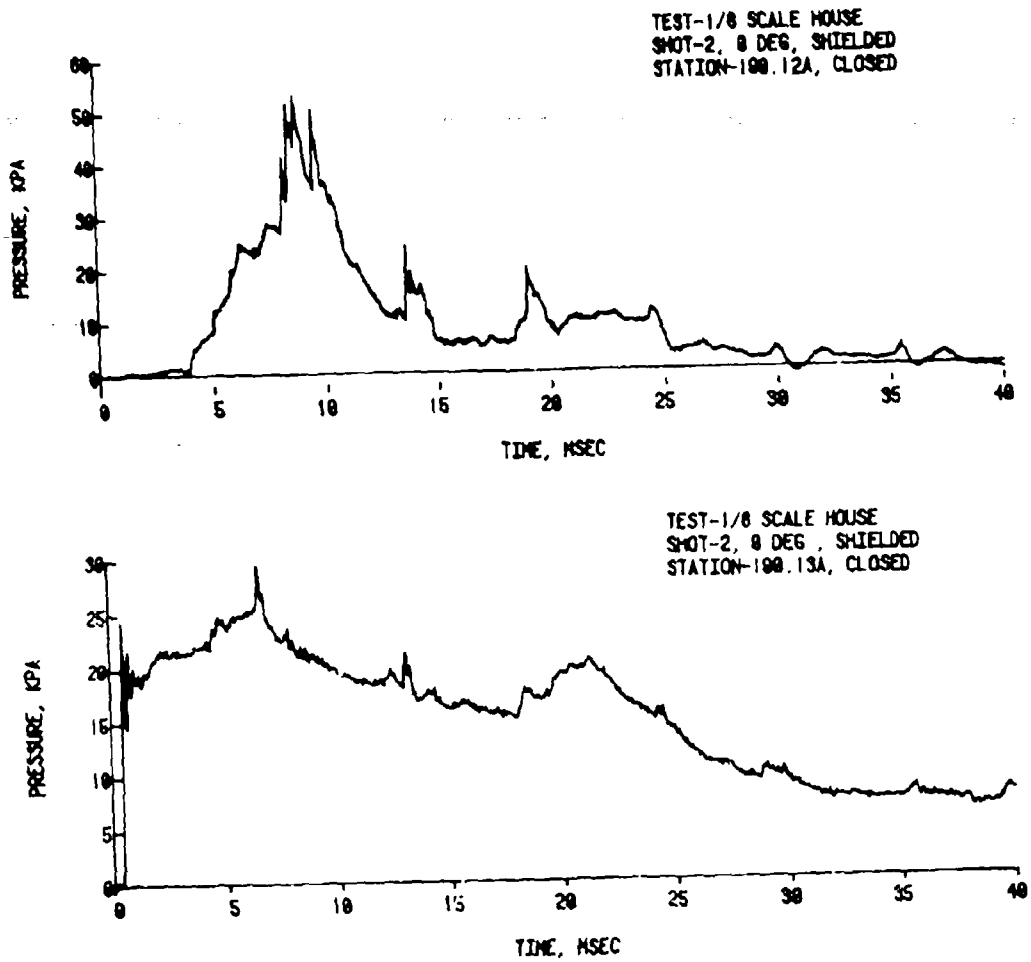


Figure A-5. Records from shielded model house, 0 degrees, Stations 190.12A and 190.13A, Shot 2.

APPENDIX B

Pressure-Time Histories, Shot 3

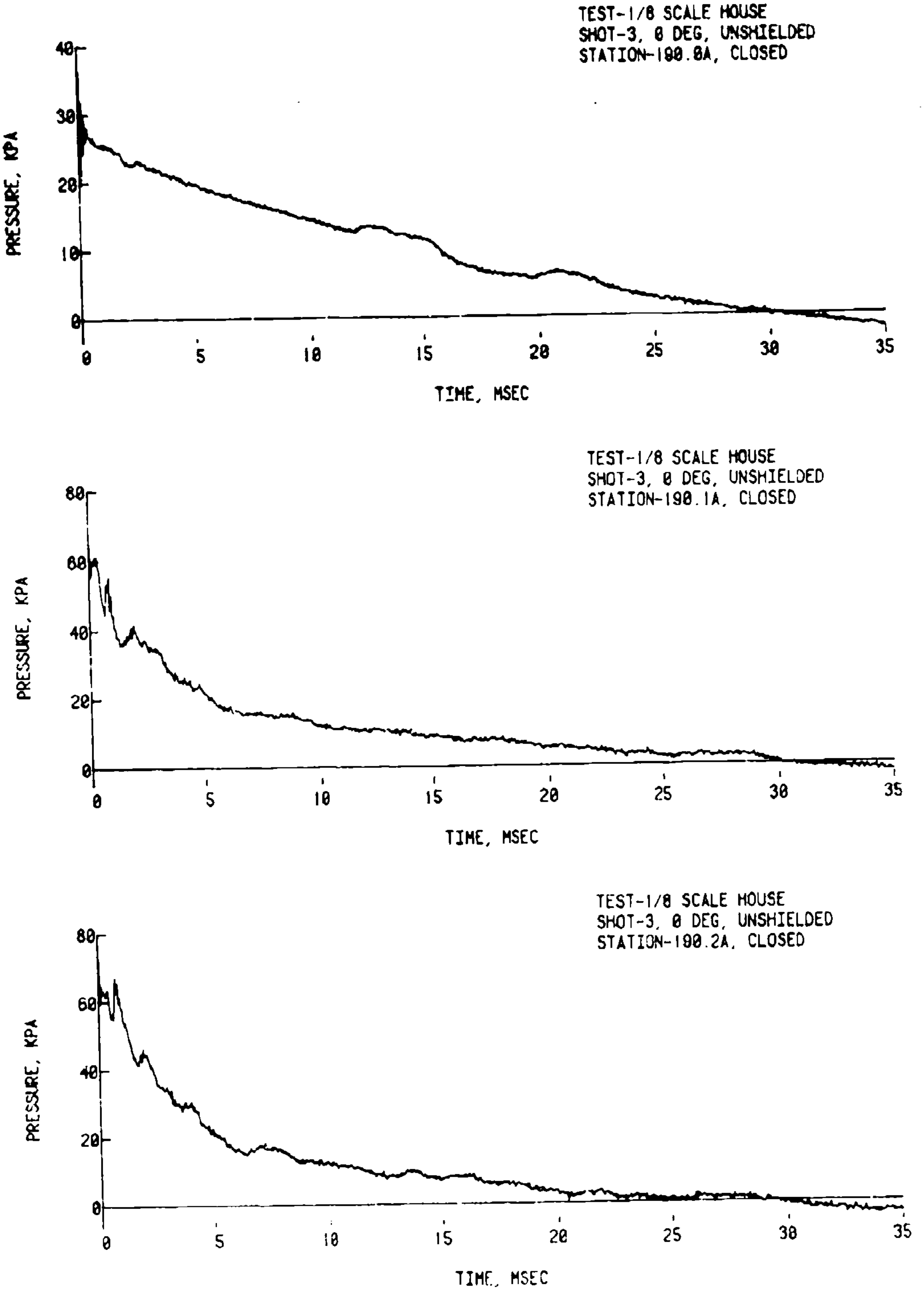
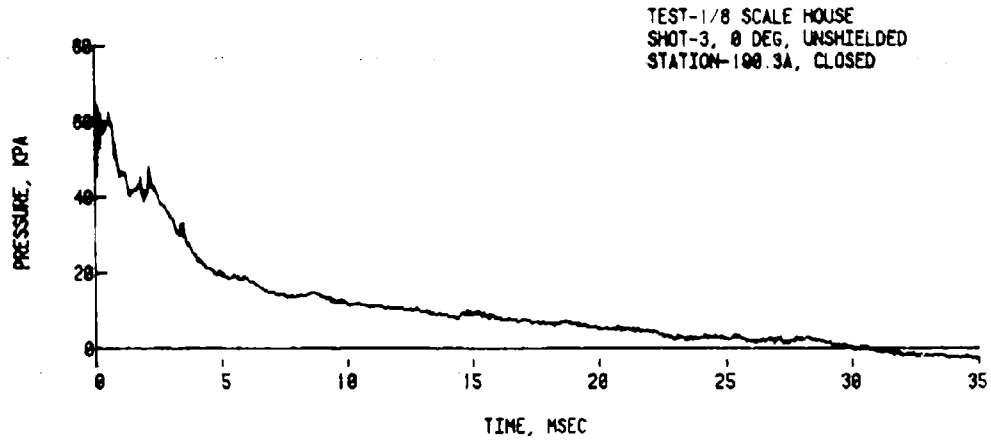
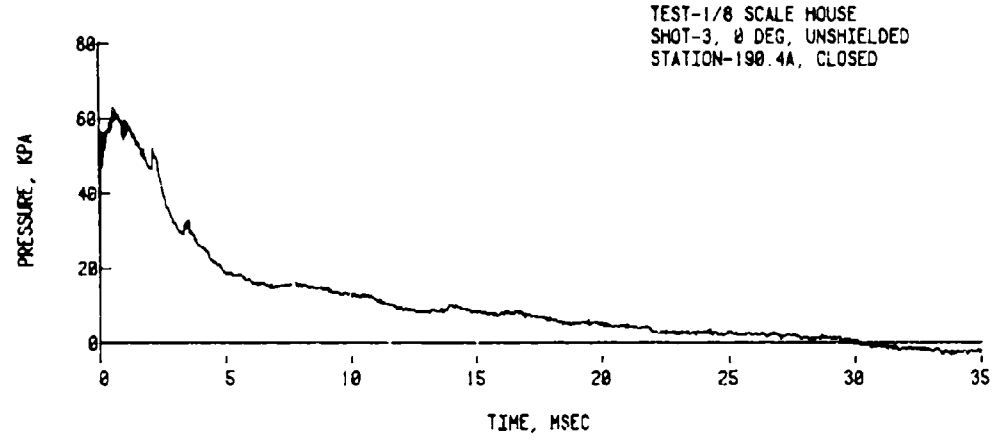


Figure [illegible]. Records from unshielded model house, [illegible] scale, Stations 190.0A, 190.1A, and 190.2A, Shot 3.





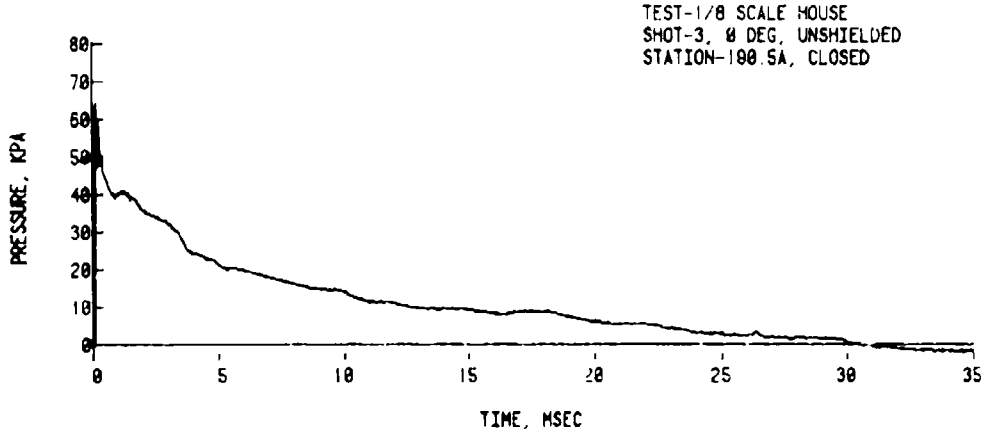
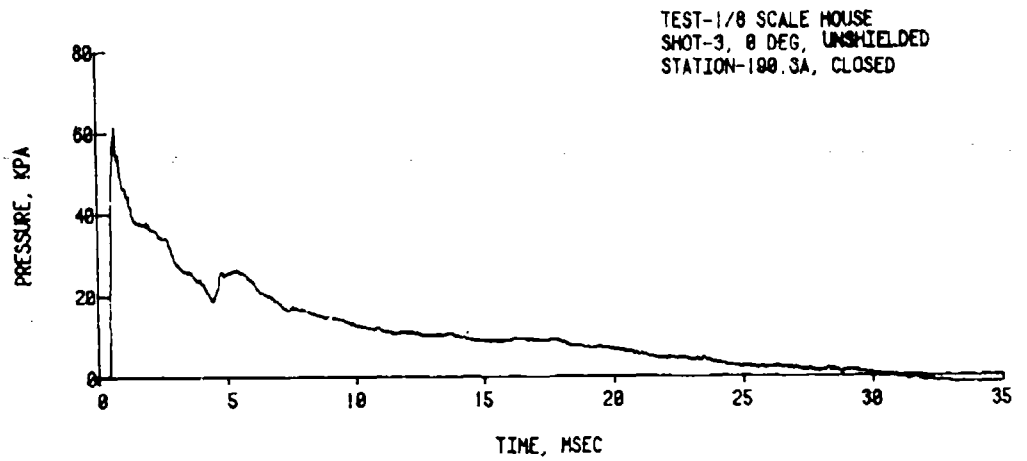
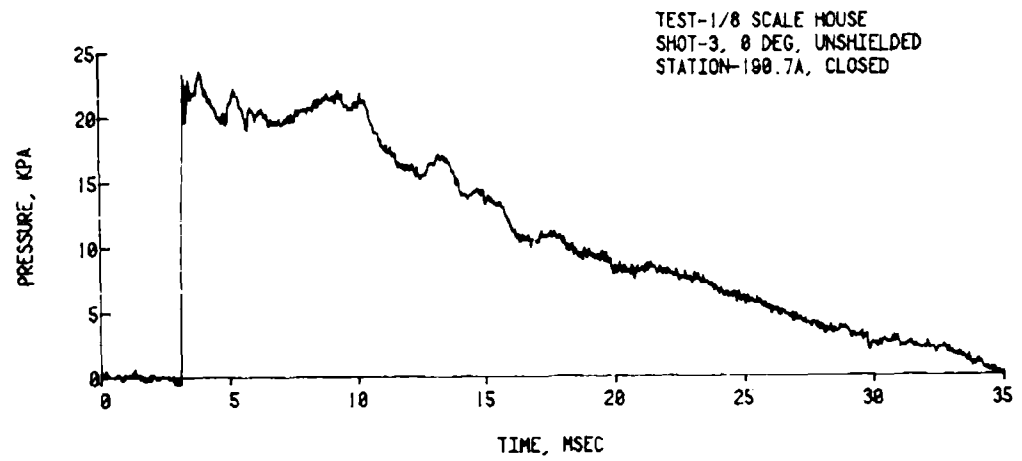


Figure B-2. Records from unshielded model house, 0 degrees, Station 190.5A, 190.3A, and 190.4A, Shot 3.





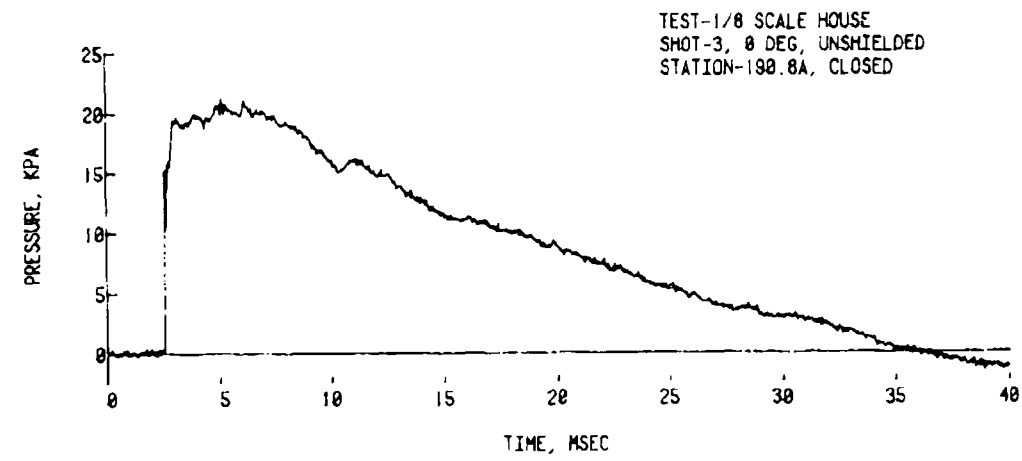


Figure B-1. Records from unshielded model houses, 0 degrees, Stations 190.6A, 190.7A, and 190.8A, Shot 3

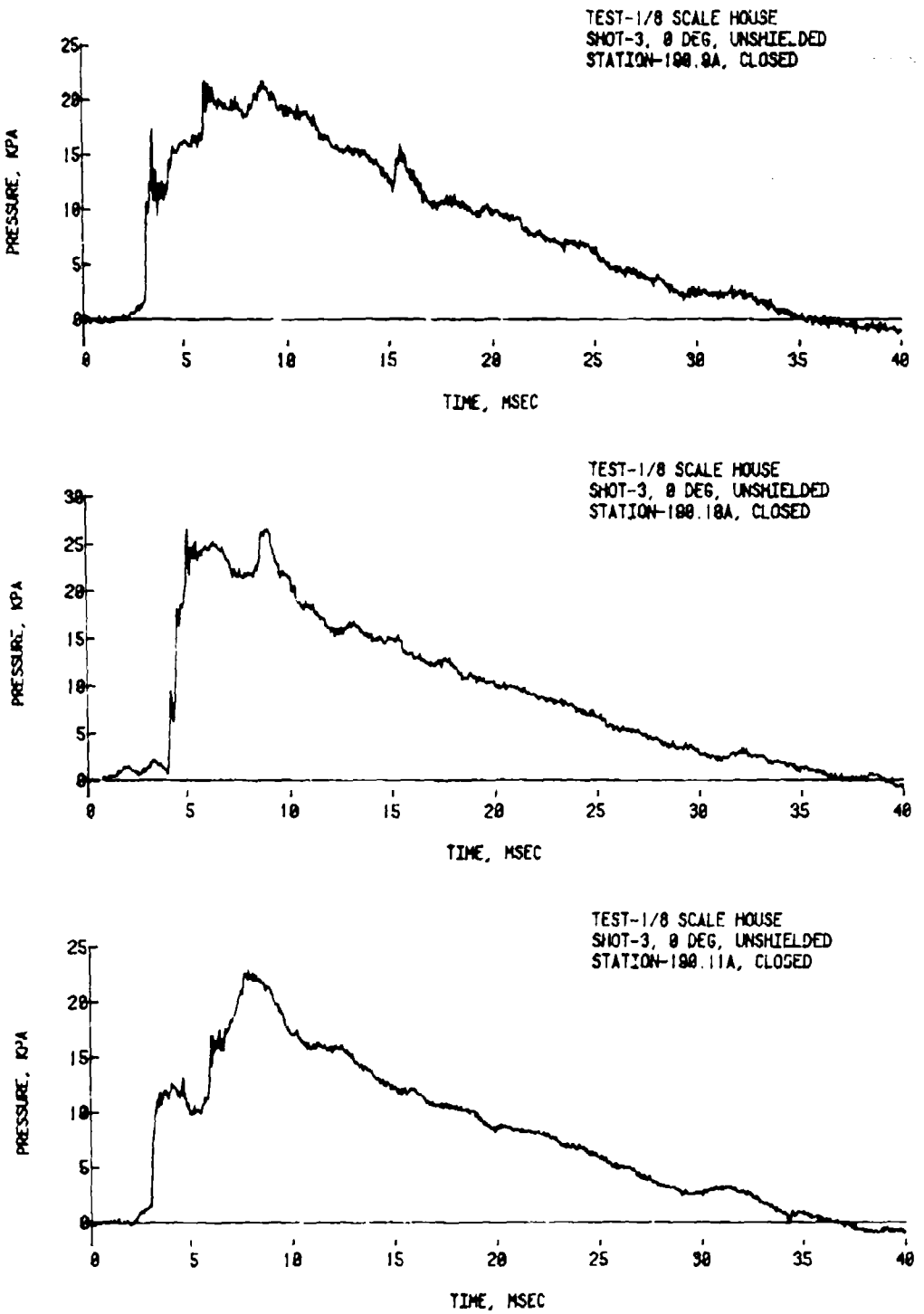
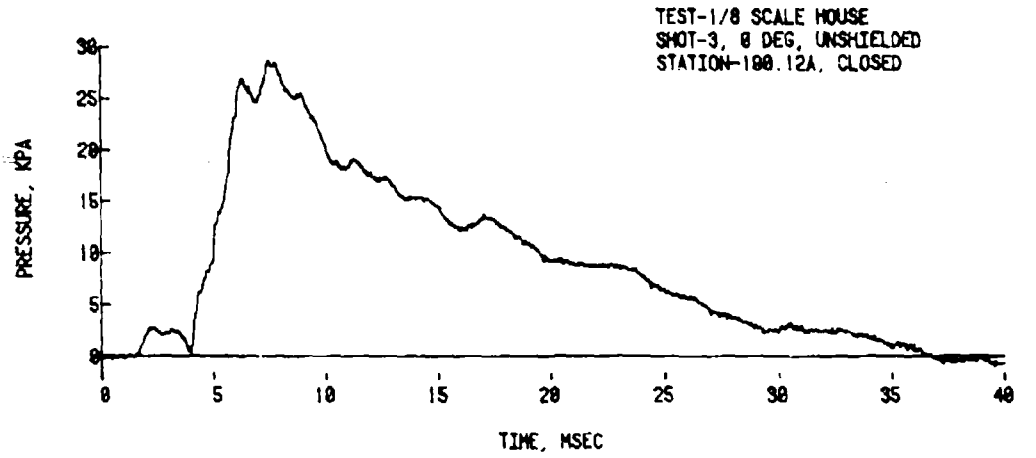


Figure B-1. Records from unshielded model house, 0 degrees, Stations 190.9A, 190.10A, and 190.11A, Shot 3.



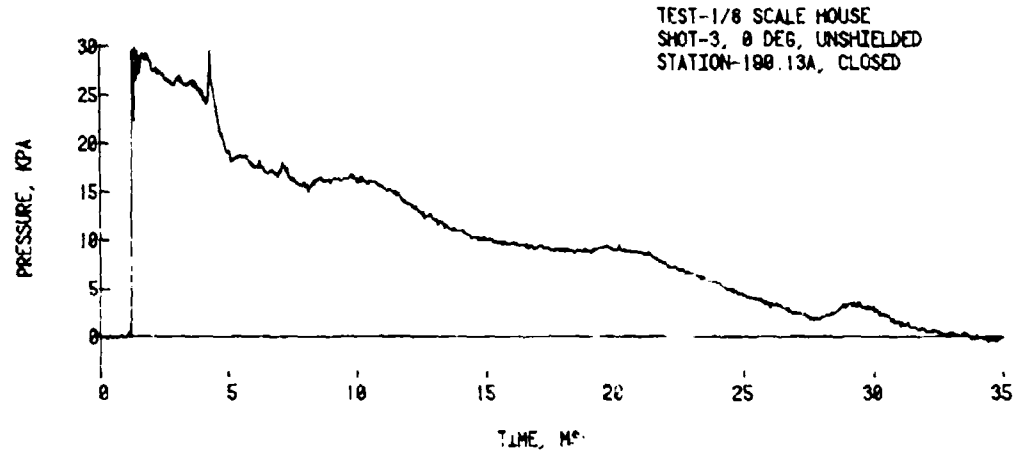
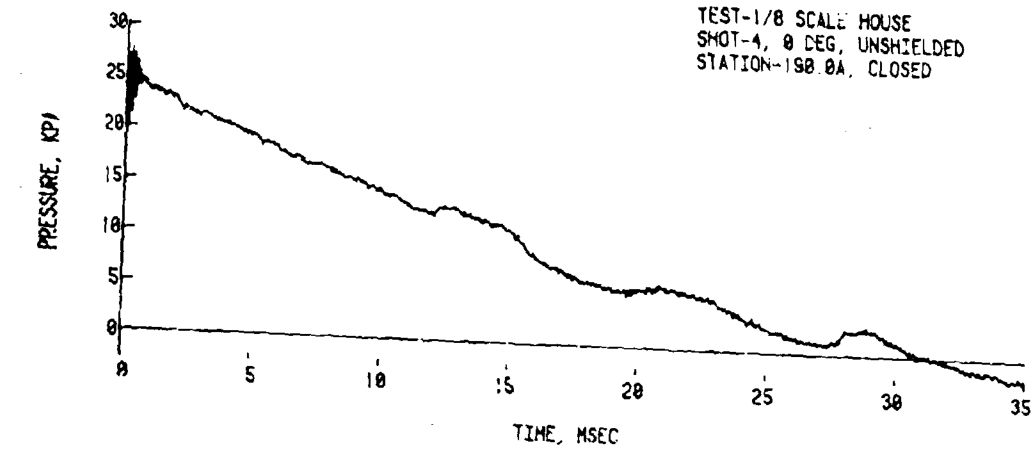
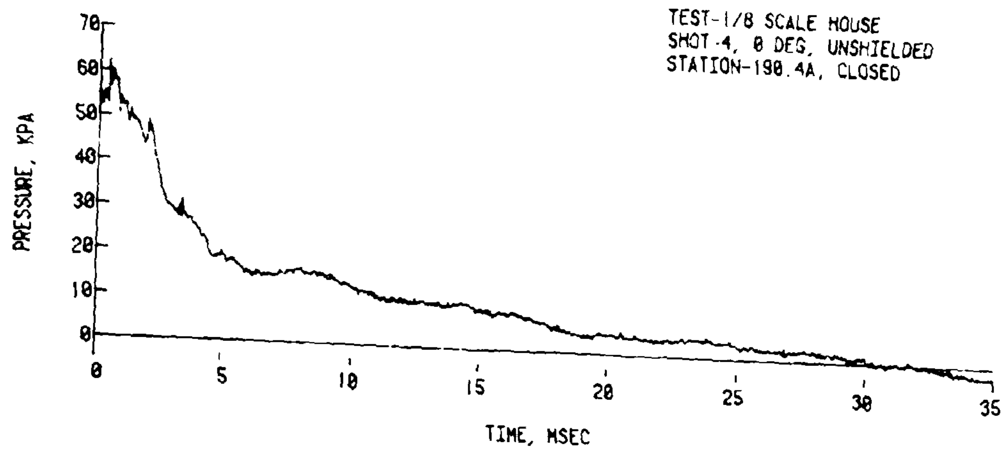


Figure B-5. Records from unshielded model houses, 0 degrees, Stations 190.12A and 190.13A, Shot 3.

APPENDIX C

Pressure-Time Histories, Shot 4





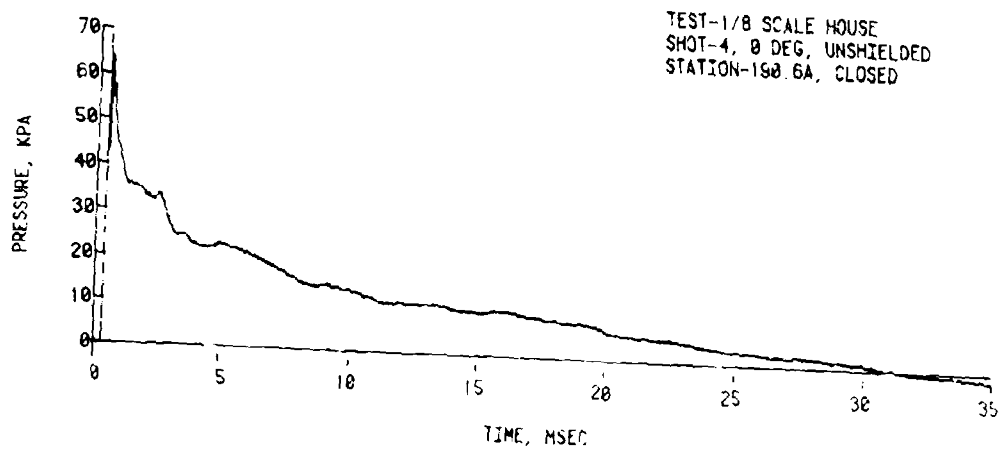


Figure [illegible]. Records from unshielded [illegible] house, [illegible] Stations 190.0A, 190.4A, and 190.6A, [illegible]

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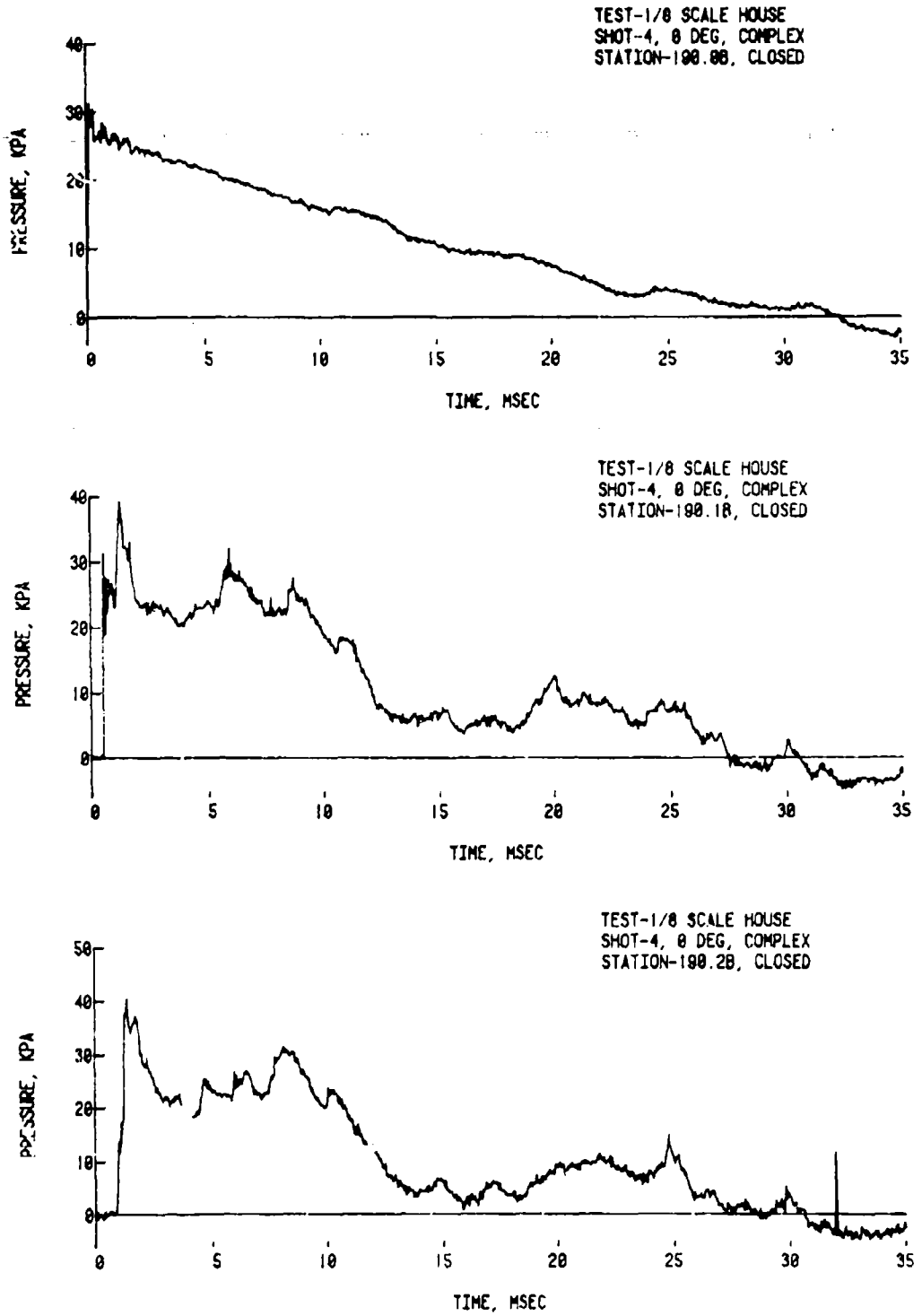


re C-2. Records from model house in complex, 0 degrees, Stations 190.0B, 190.1B, and 190.2B, Shot 4.

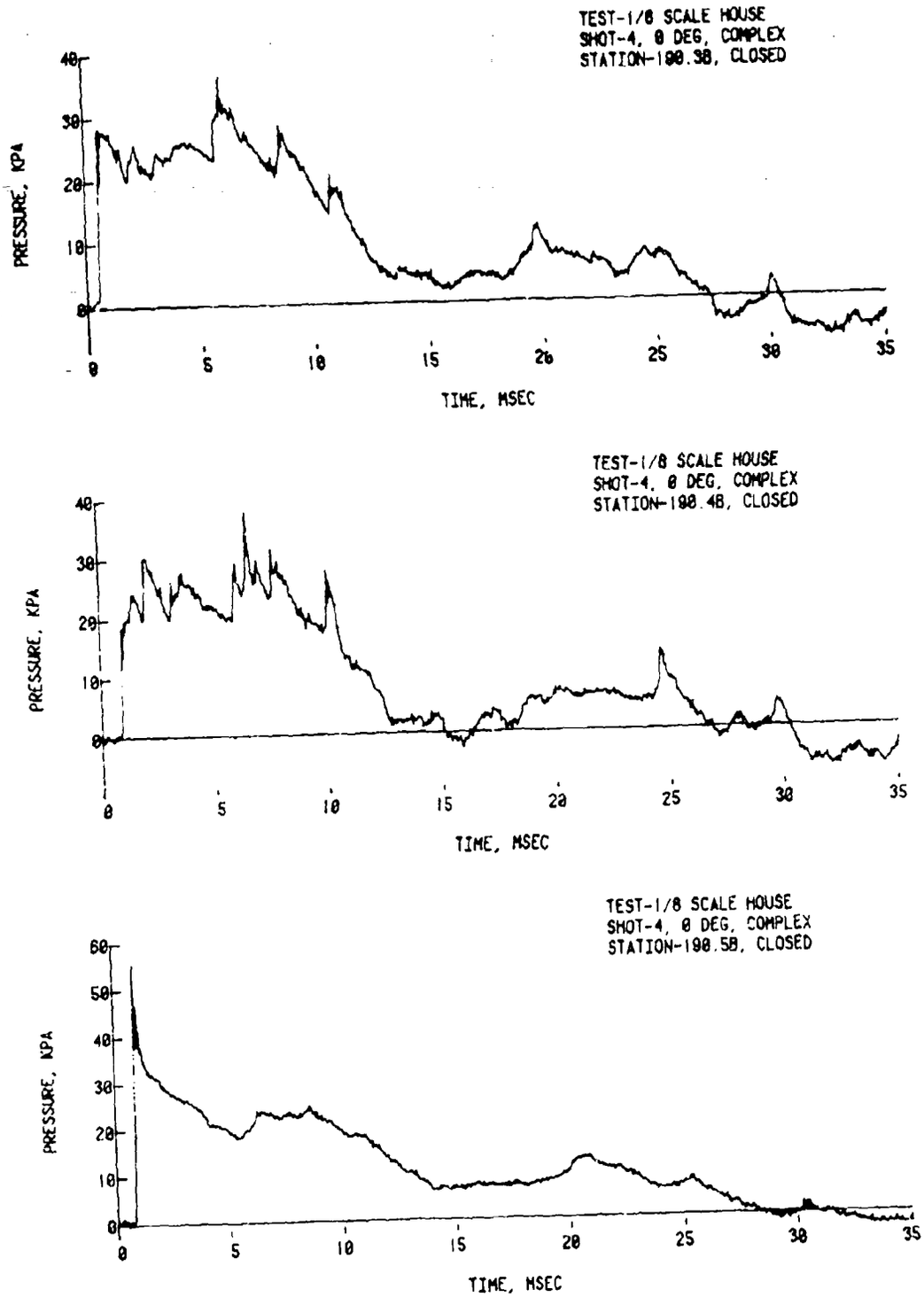


Figure C-x. Records from model house in complex, 0 degrees, Stations 190.3B, 190.4B, and 190.5B, Shot 4.

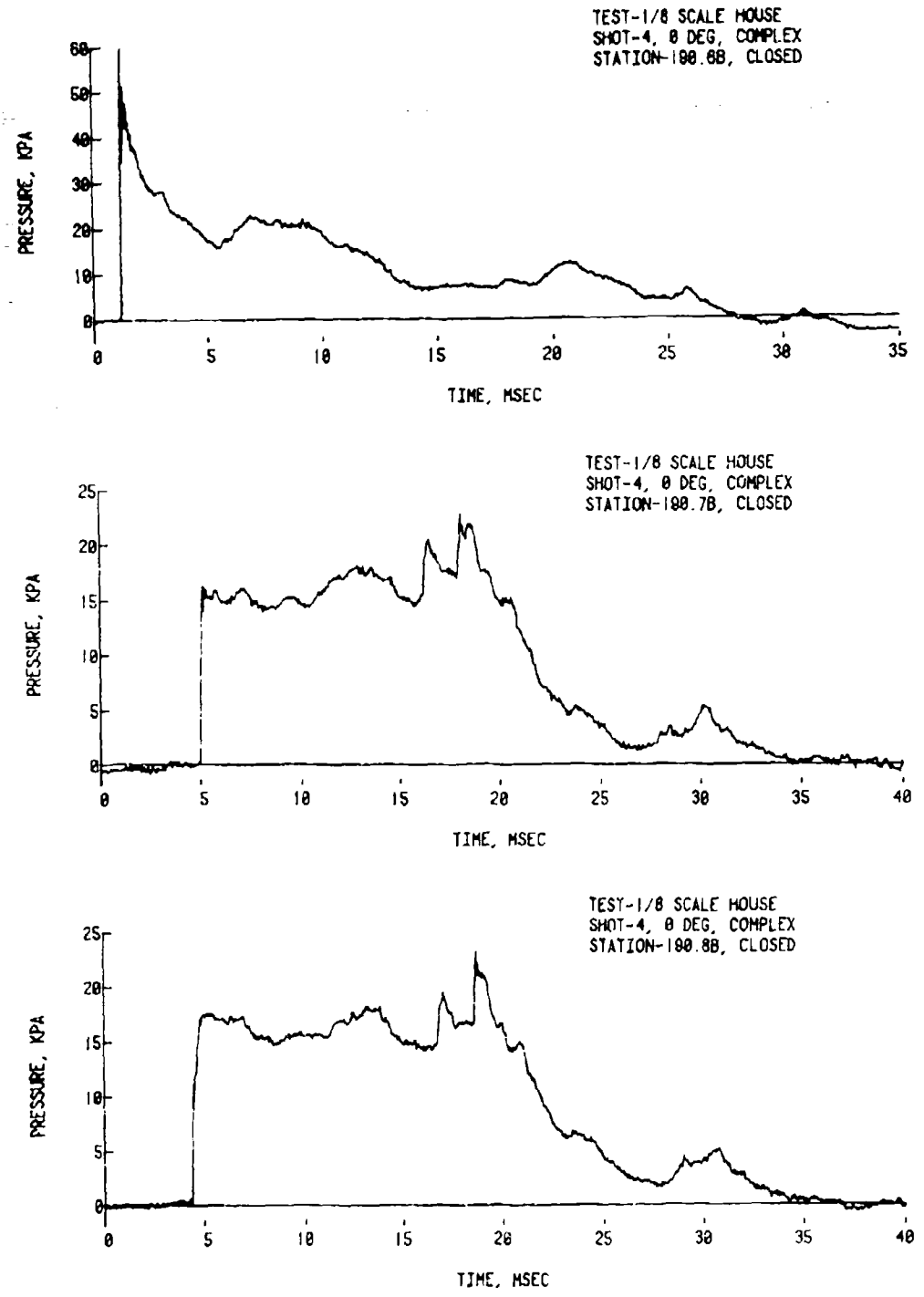
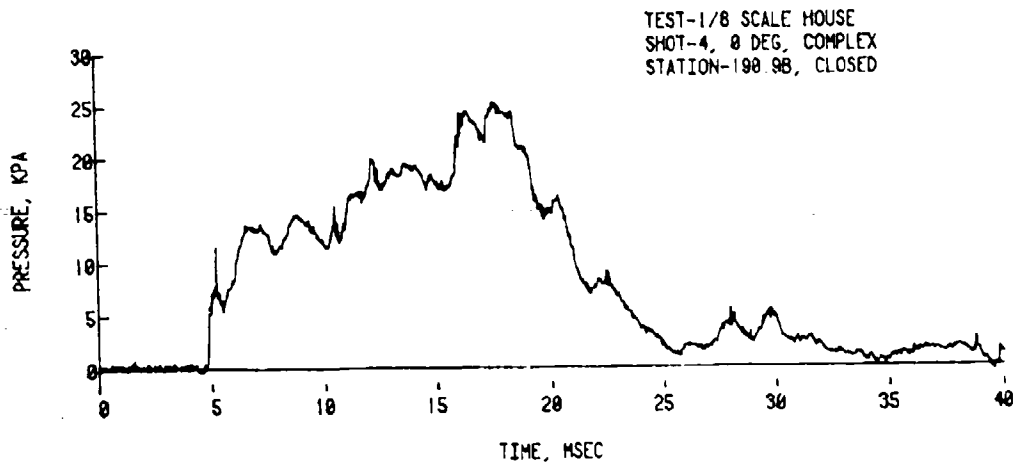
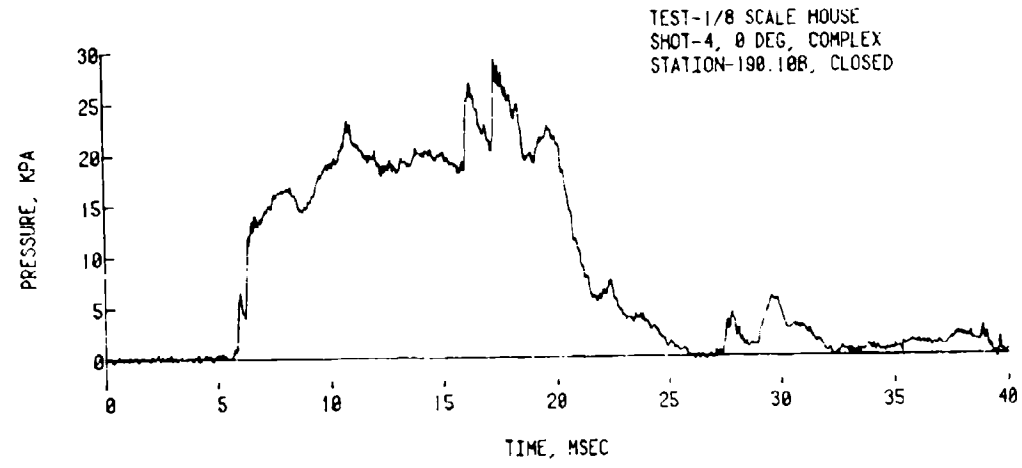


Figure C-1. Records from model house in complex, 0 degrees, Stations 180.6B, 180.7B, and 180.8B, Shot 4.





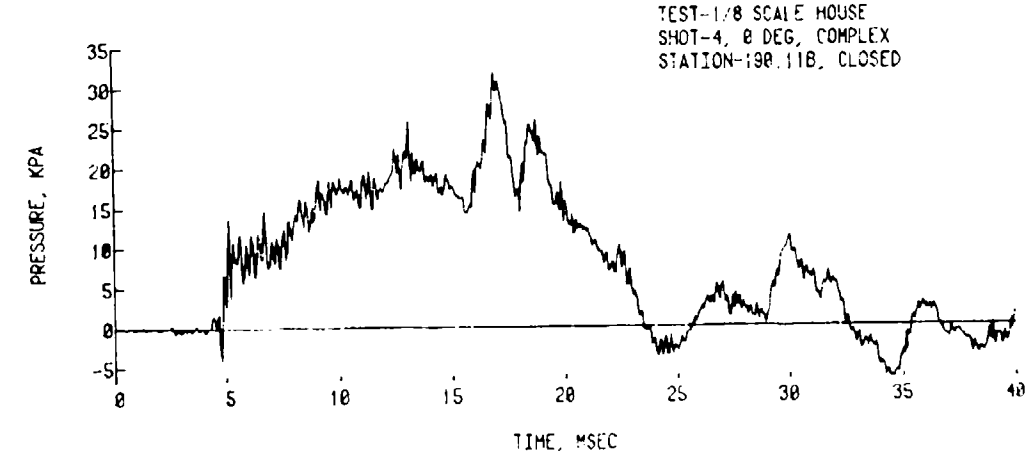


Figure C-1. Records from model house in complex, 0 degrees, Stations 190.9B, 190.10B, and 190.11B, Shot 4

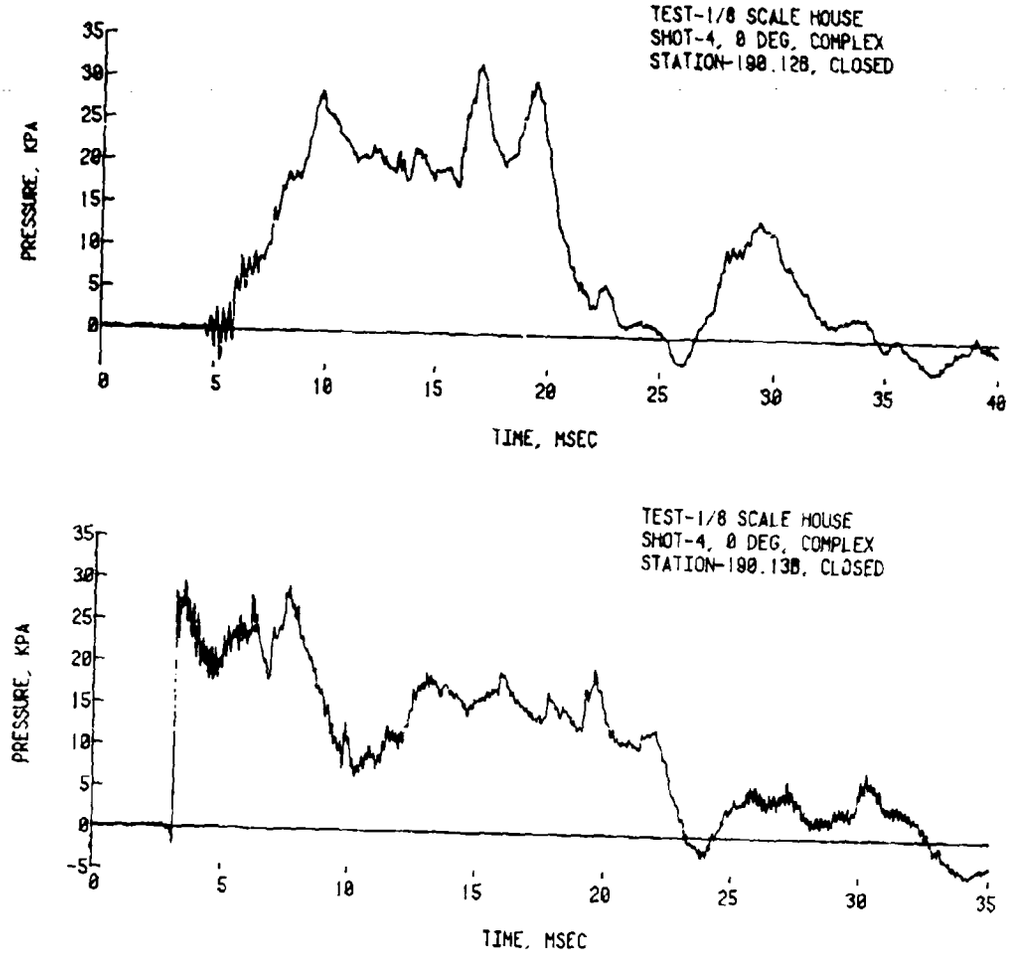


Figure C-6. Records from model house in complex, 0 degrees, Stations 190.12B and 190.13B, Shot 4.

APPENDIX D

Pressure-Time Histories, Shot 5

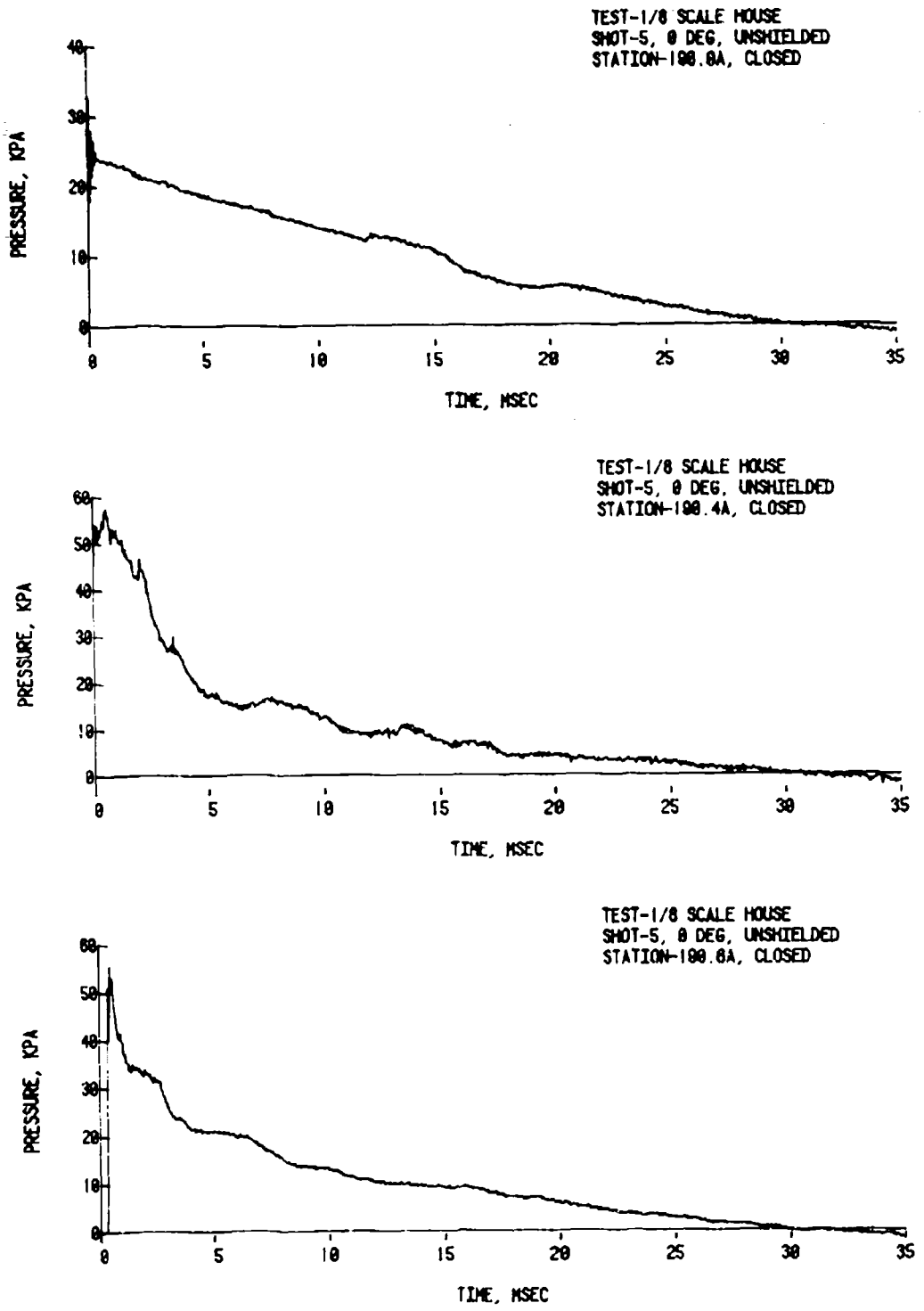


Figure D-1. Records from unshielded model house, 0 degrees, Stations 198.8A, 198.4A, and 198.6A, Shot 5.

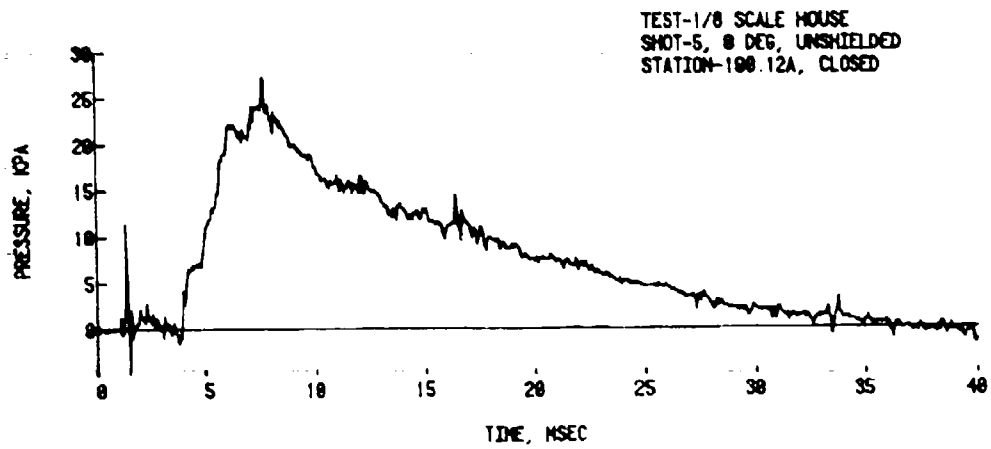


Figure D-2. Records from unshielded model house, 0 degrees, Station 190.12A, Shot 5.

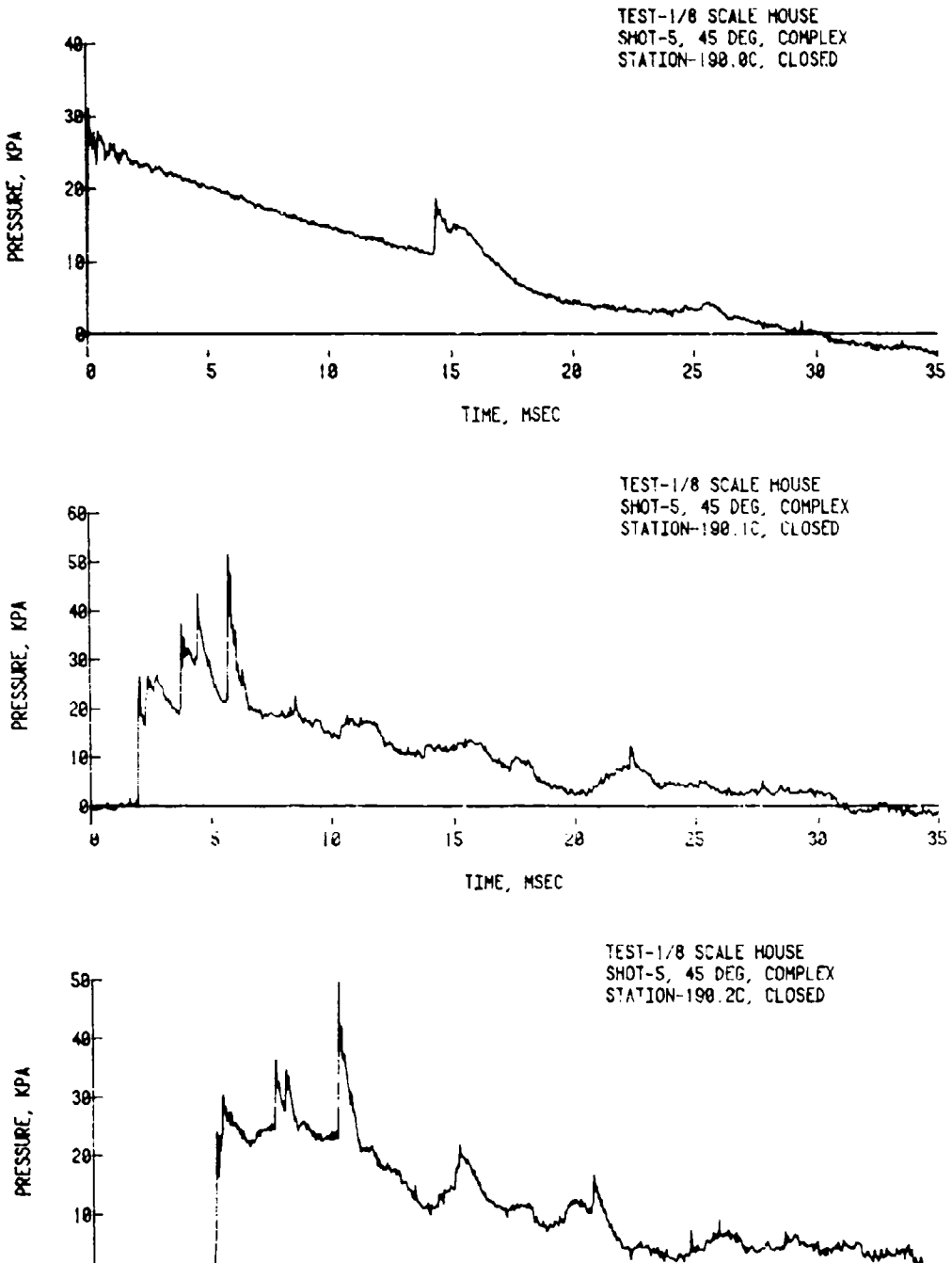
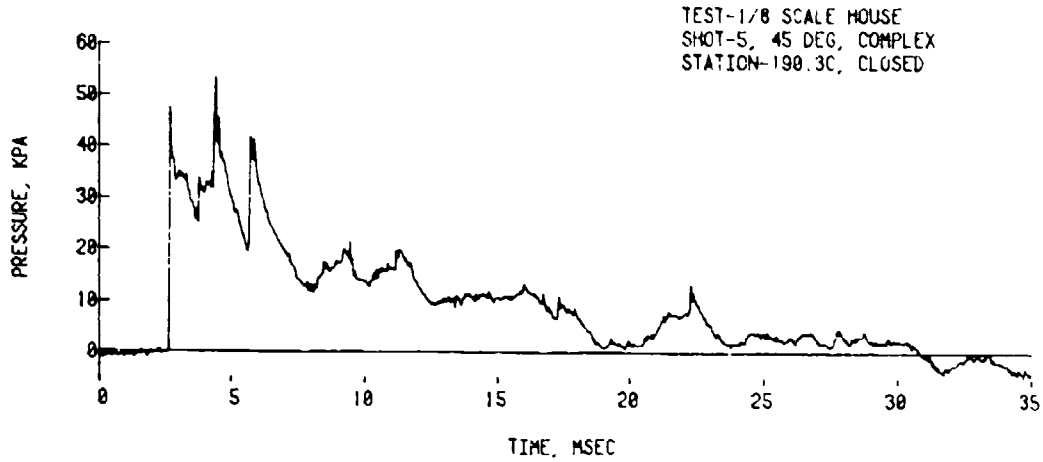
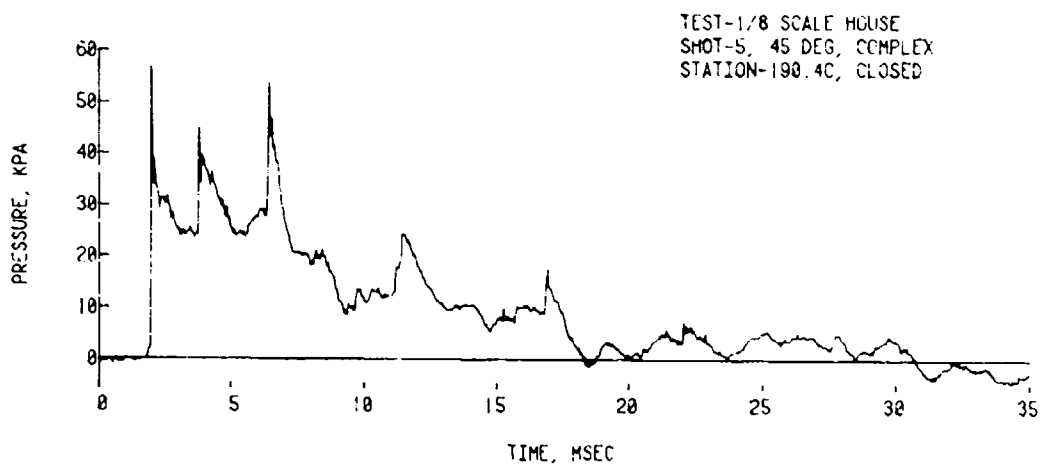


Figure 3-5. Records from scaled house in complex, 45 degrees, Stations 190.0C, 190.1C, and 190.2C, Shot 5.





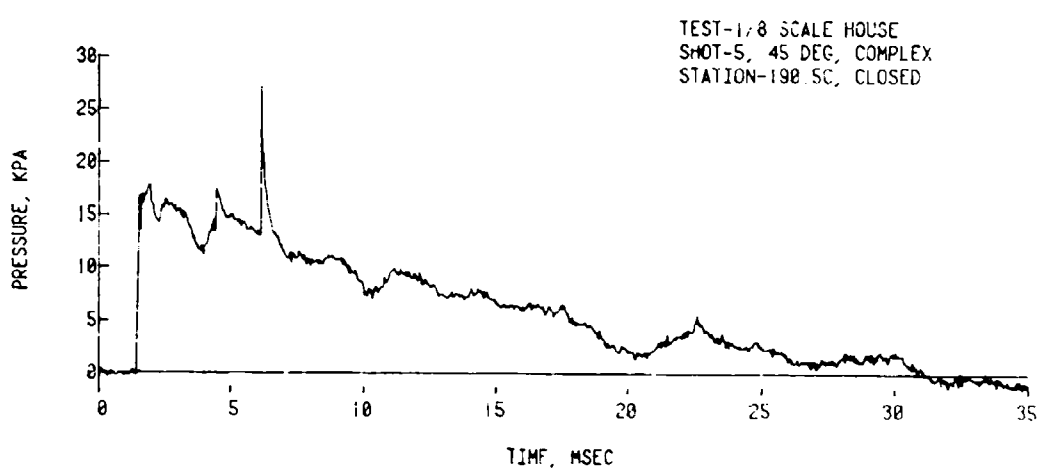
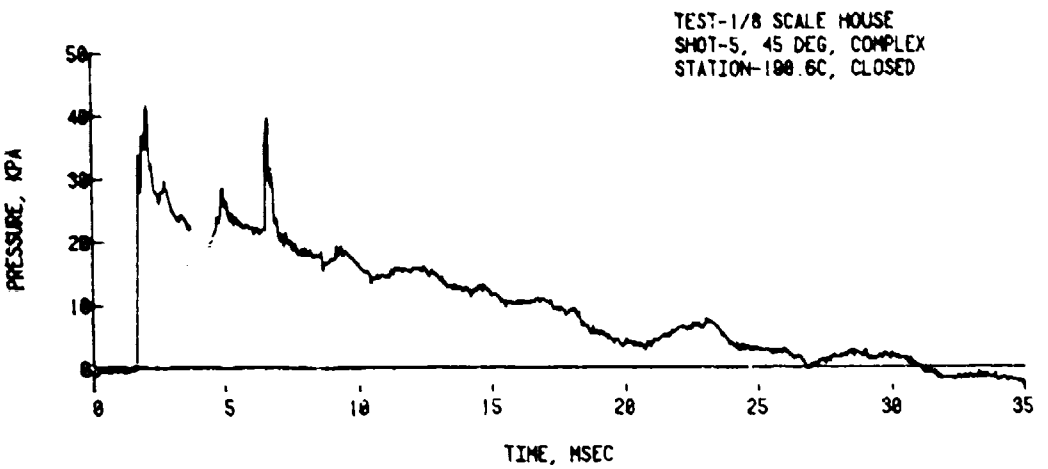
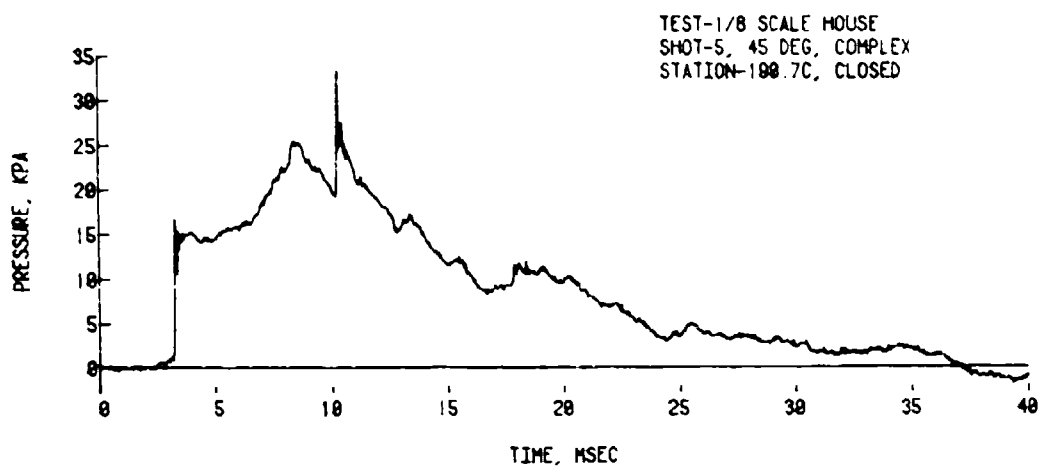


Figure D-3. Records from model house in complex, 45 degrees, Stations 190.3C, 190.4C, and 190.5C, Shot 5





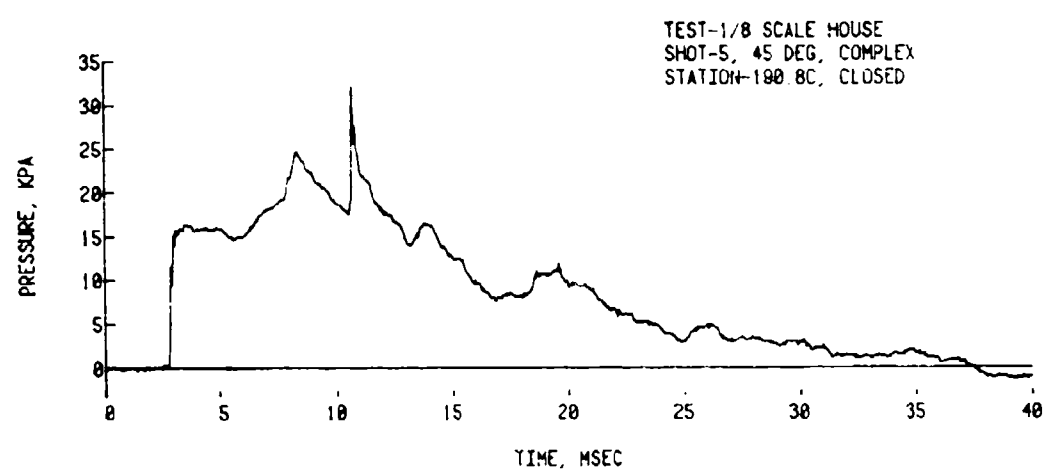
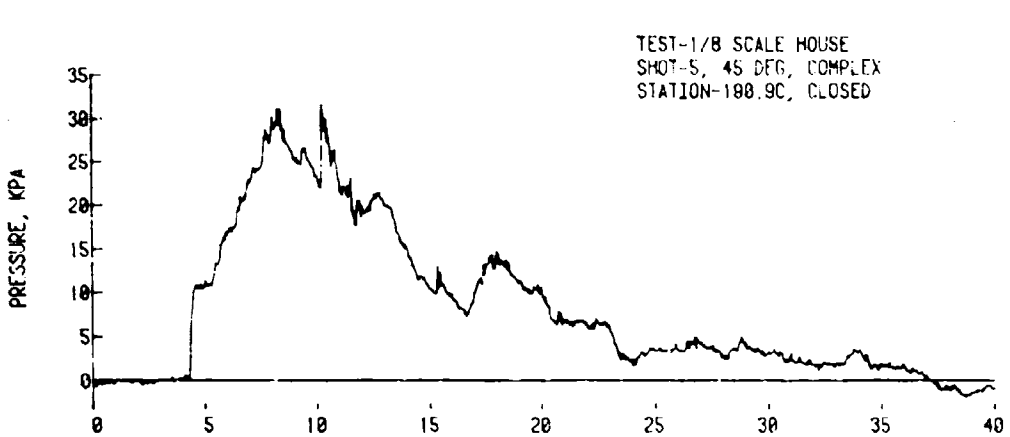
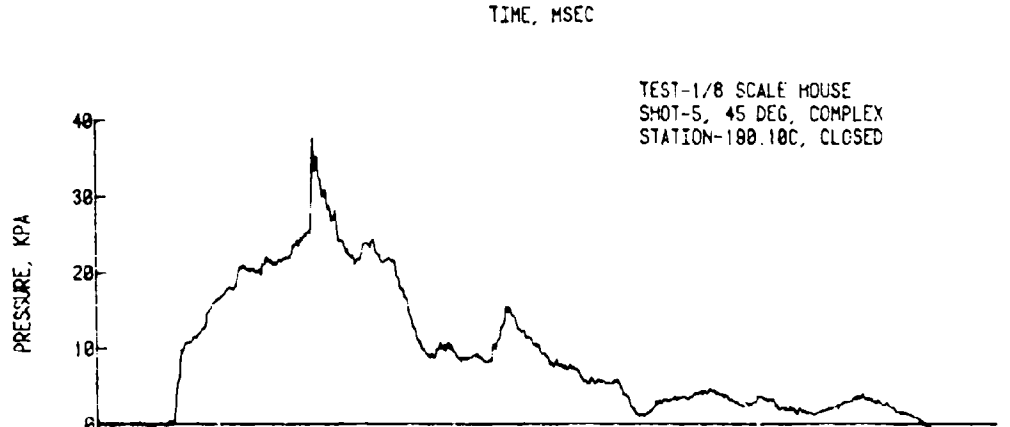


Figure D-5. Records from model house in complex, 45 degrees, Stations 190.6C, 190.7C, and 190.8C, Shot 5.





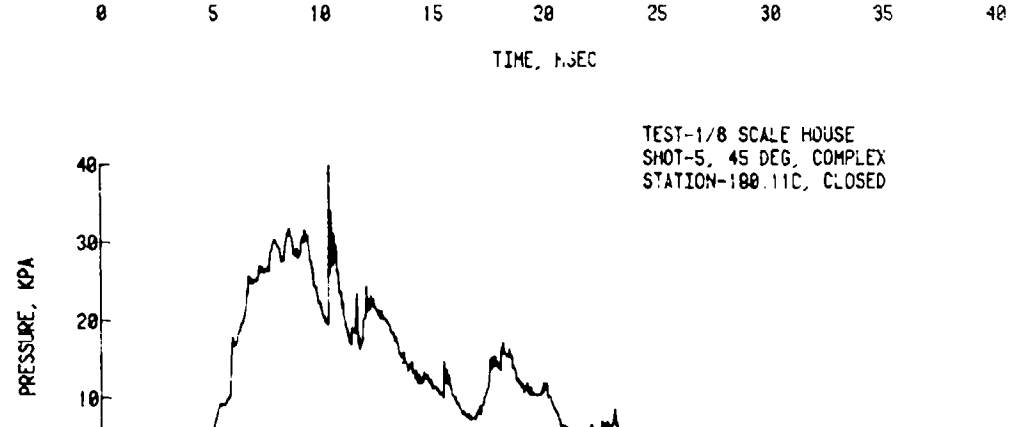


Figure B-6. Records from scale house in complex, 45 degrees, Stations 180.9C, 180.10C, and 180.11C, Shot 5.

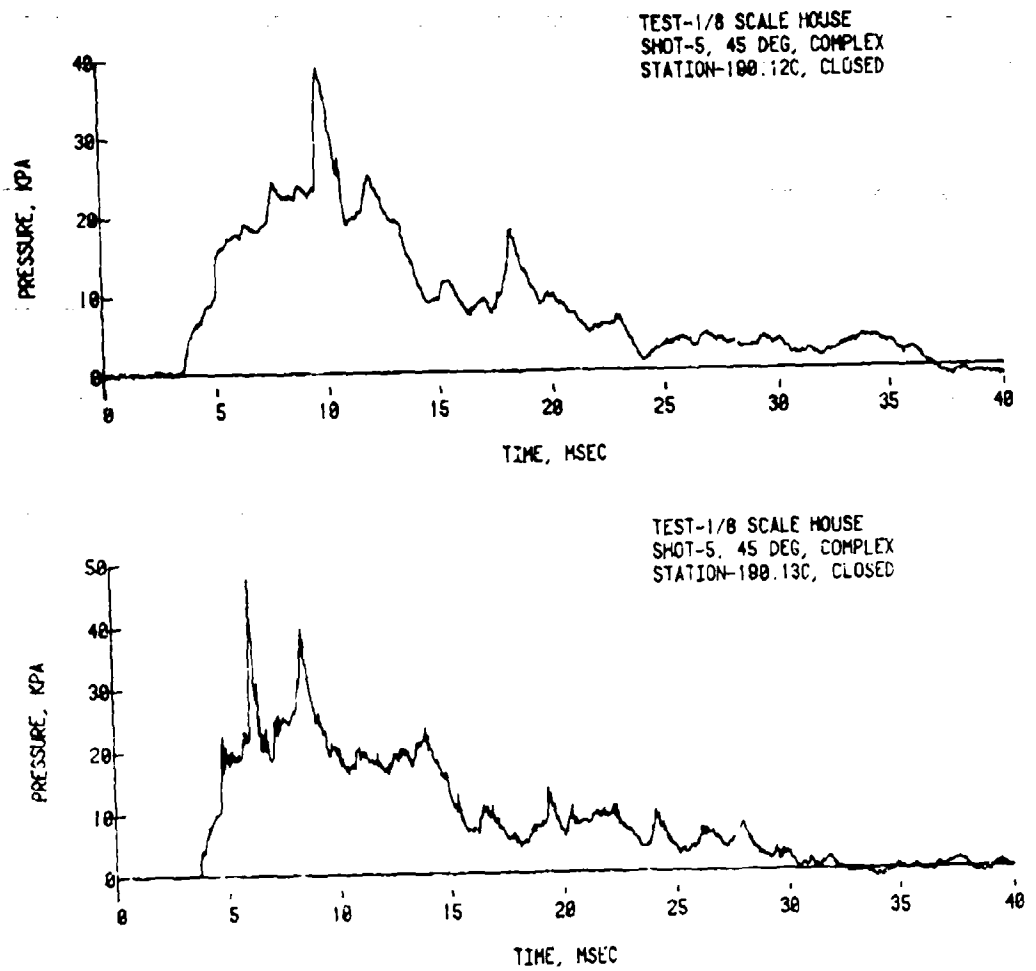


Figure D-7. Records from model house in complex, 45 degrees, Stations 190.12C and 190.13C, Shot 5.

APPENDIX E

Pressure-Time Histories, Shot 6

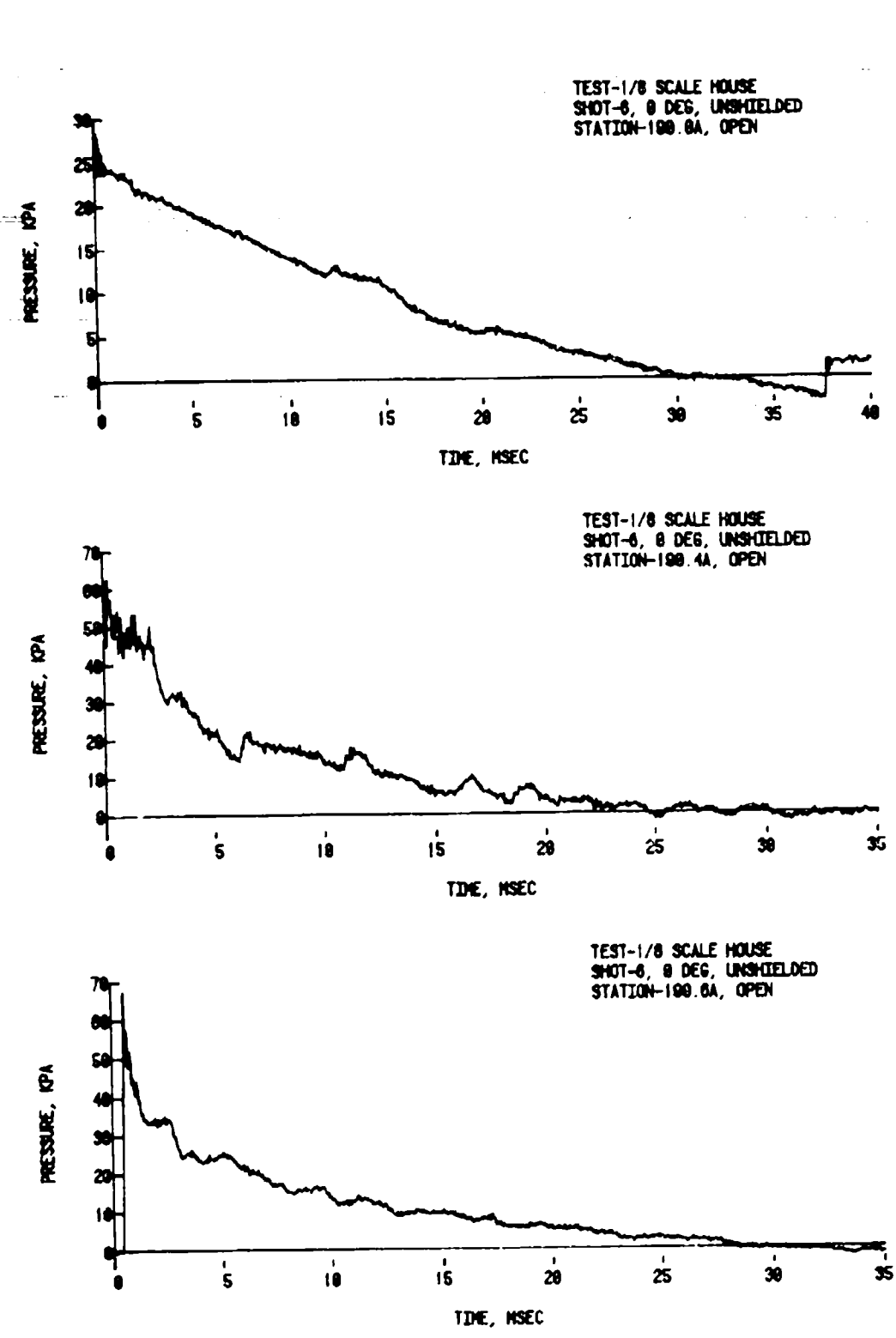
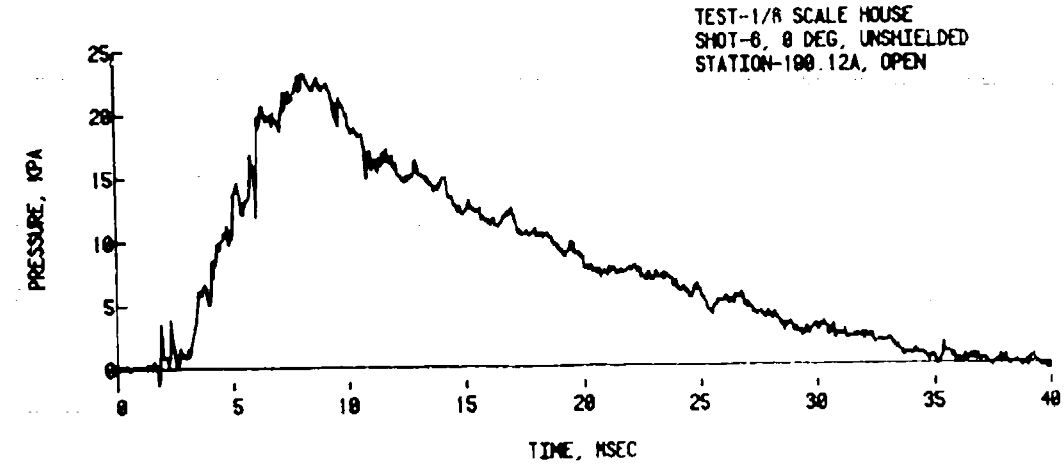
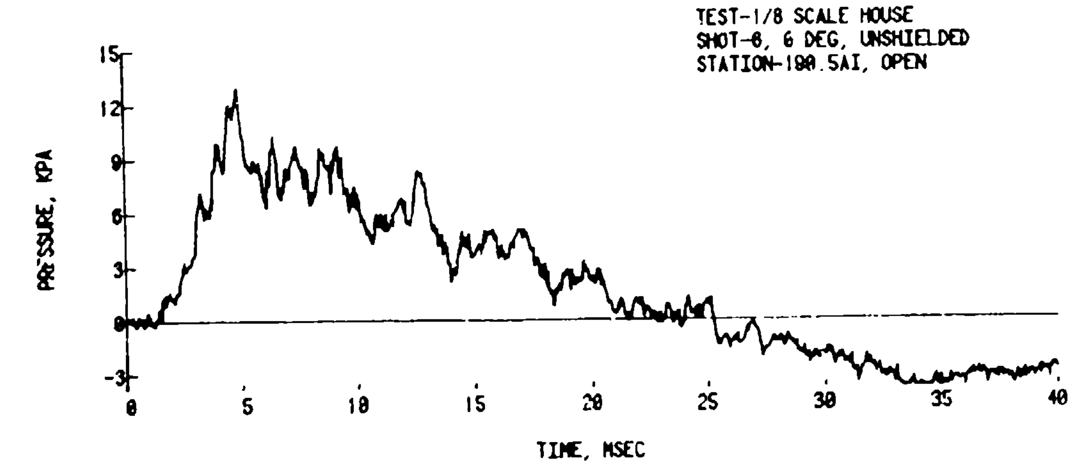


Figure I-1. Records from unshielded open model house, 0 degrees, Stations 190.0A, 190.4A, and 190.6A, Shot 6.





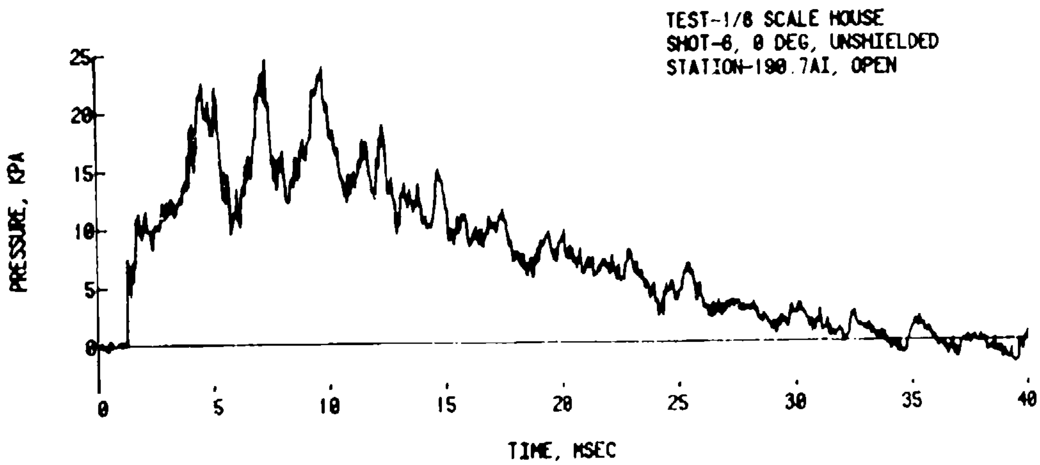


Figure [illegible]. Records from unshielded open model house, 0 degrees, Stations 190.12A, 190.5AI, and 190.7AI, Shot 6

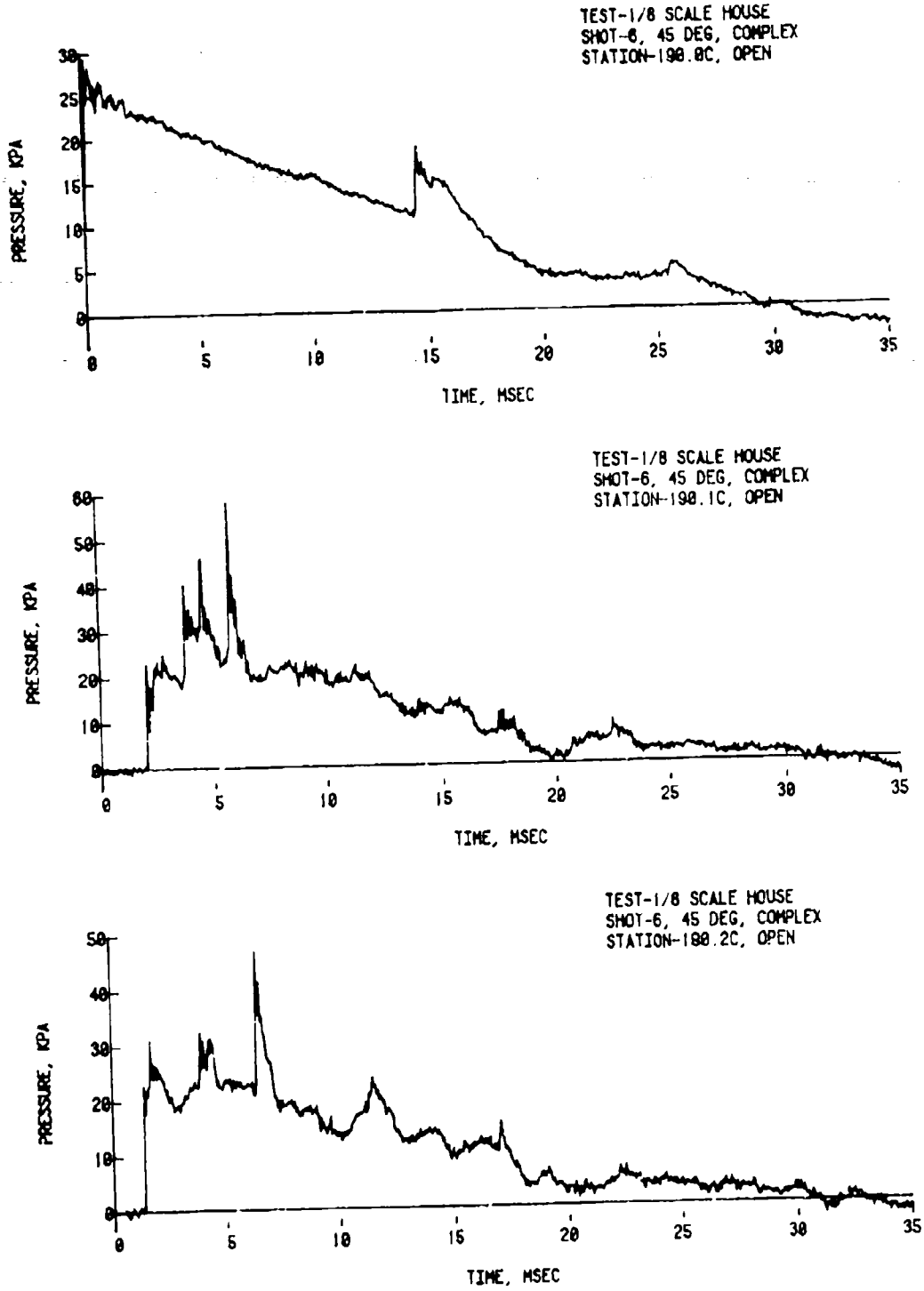
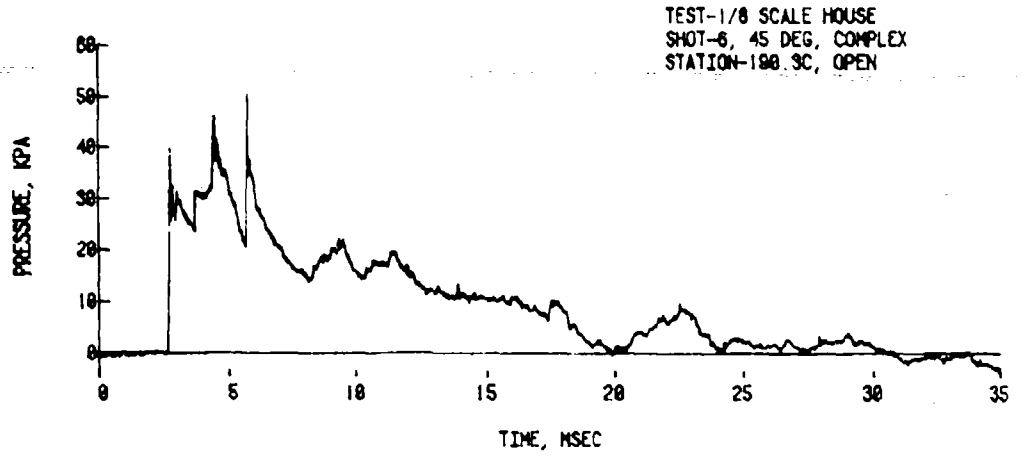
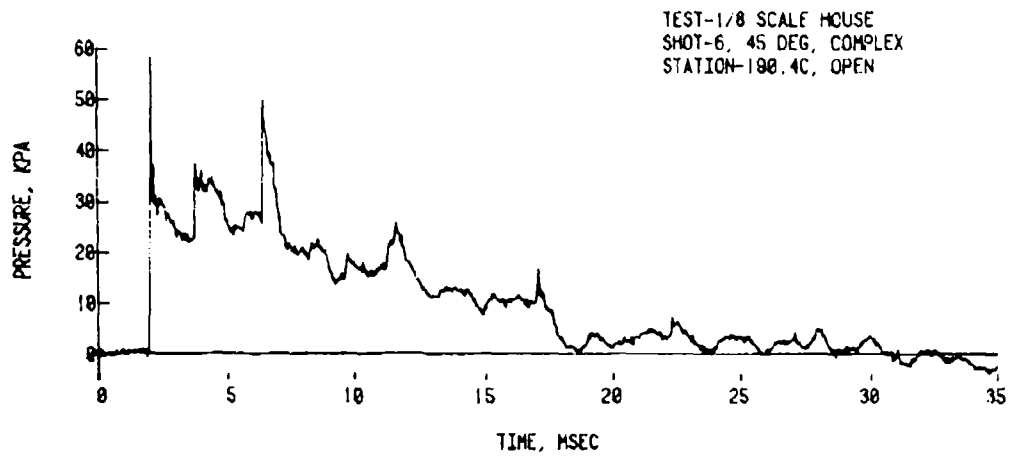


Figure I-3. Records from open model house in complex, 45 degrees, Stations 190.0C, 190.1C, and 190.2C, Shot 6.





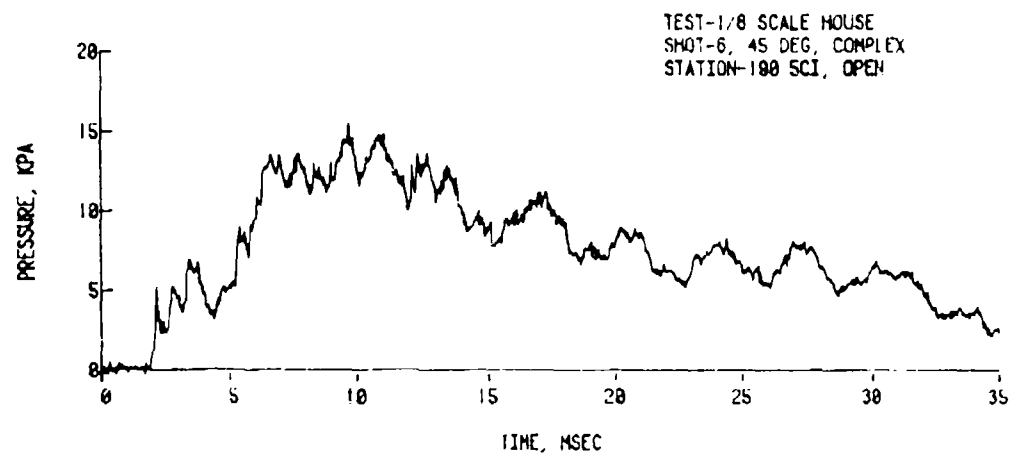
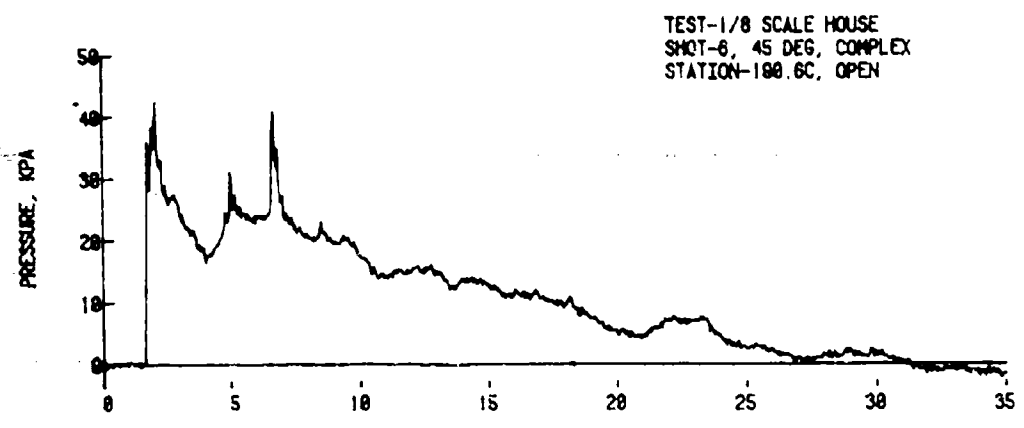
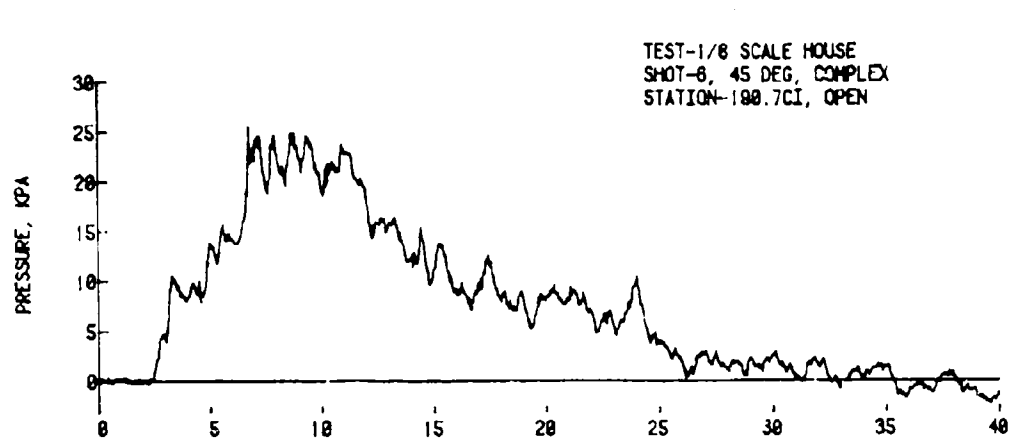


Figure [illegible]. Records from open-roof house in complex, [illegible], Stations 198.5C, 198.3C, and 198.4C, shot 6.





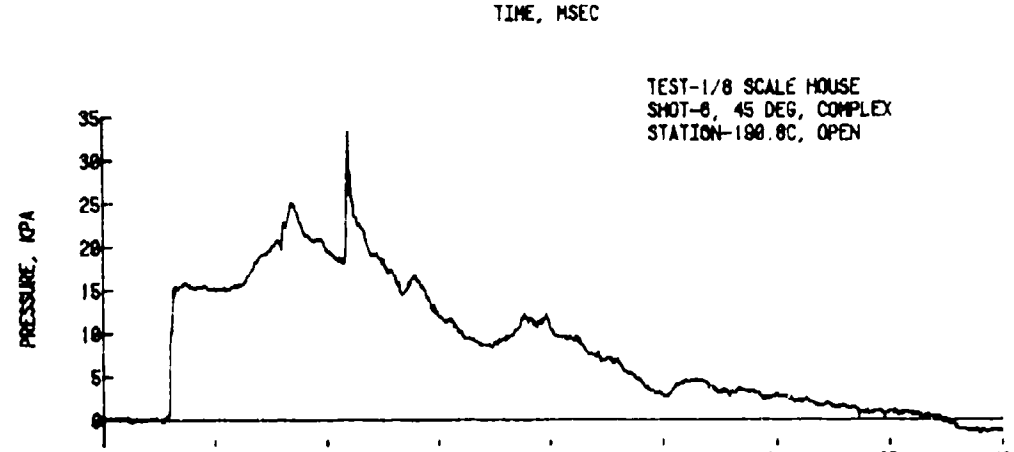
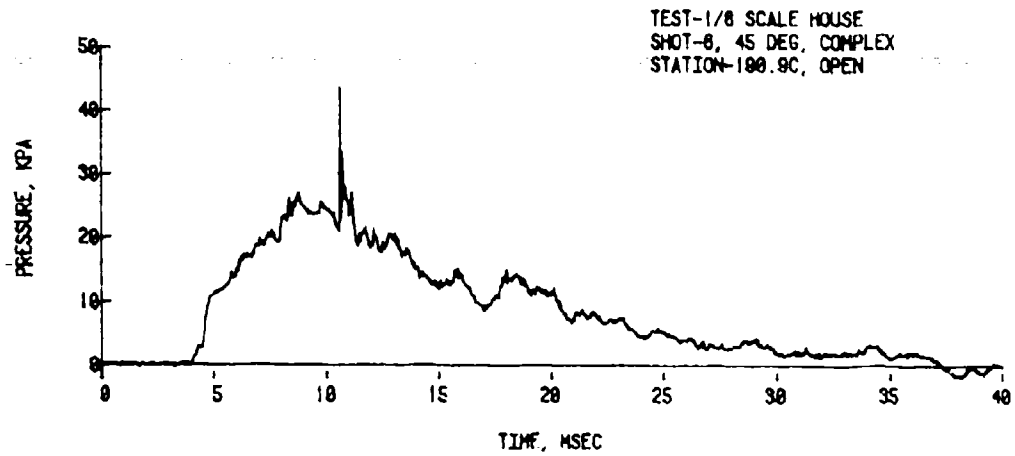
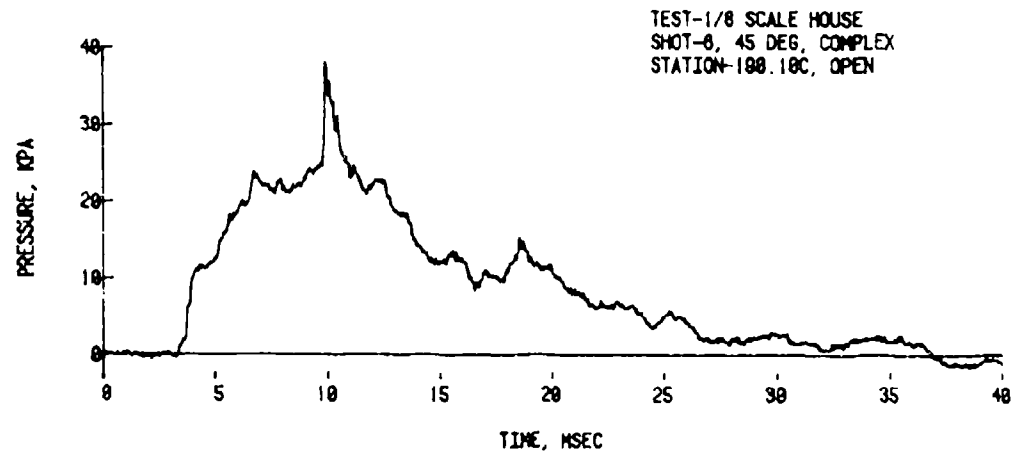


Figure 1-5. Records from open model house in complex, 45 degrees, Stations 190.6C, 190.7CI, and 190.8C, Shot 6





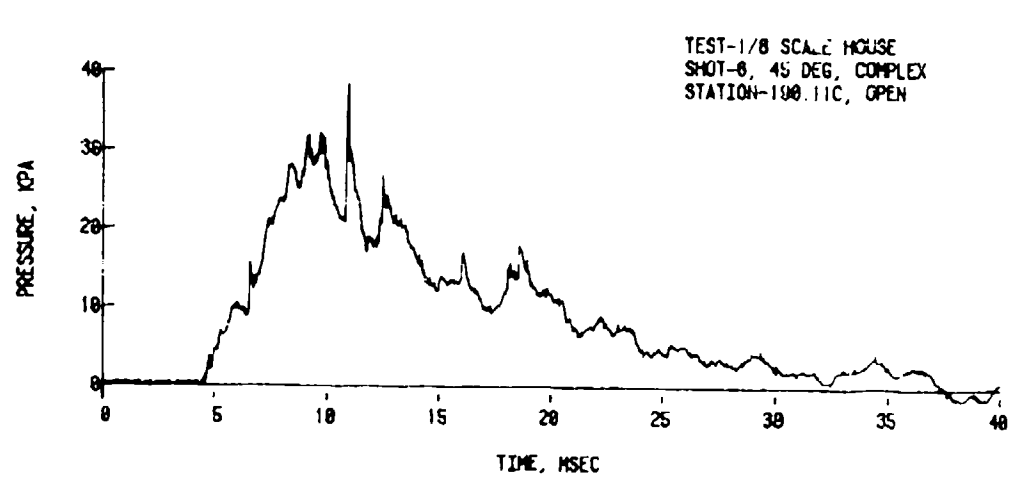


Figure C-6. Records from open model house in complex, Incidence, Stations 100.9C, 100.10C, and 100.11C, Sheet 3

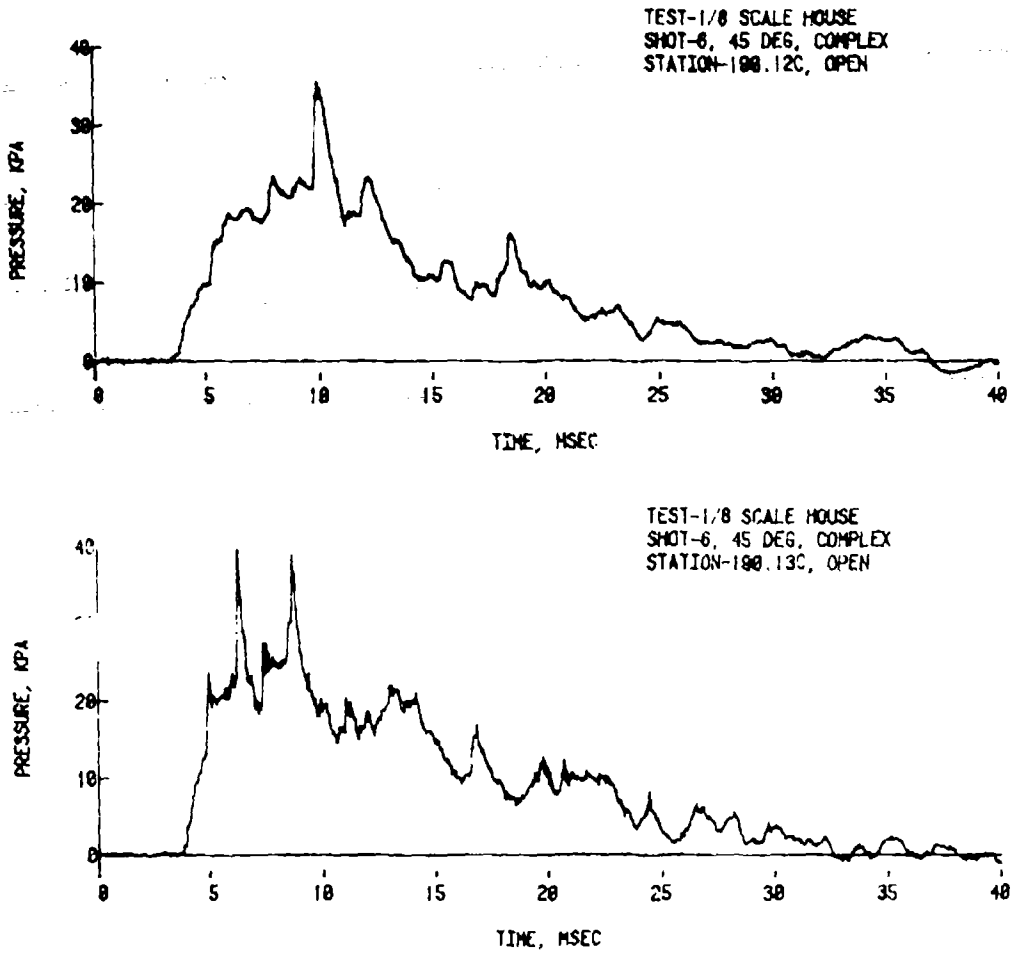
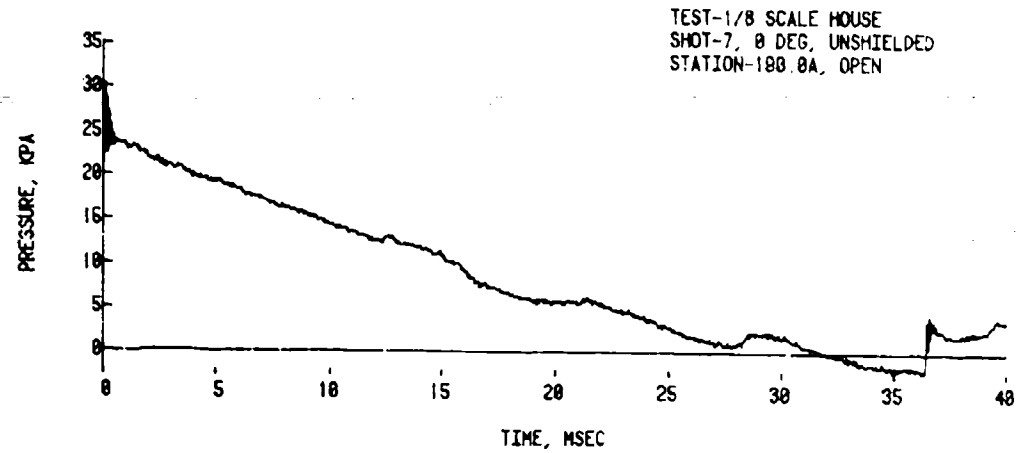
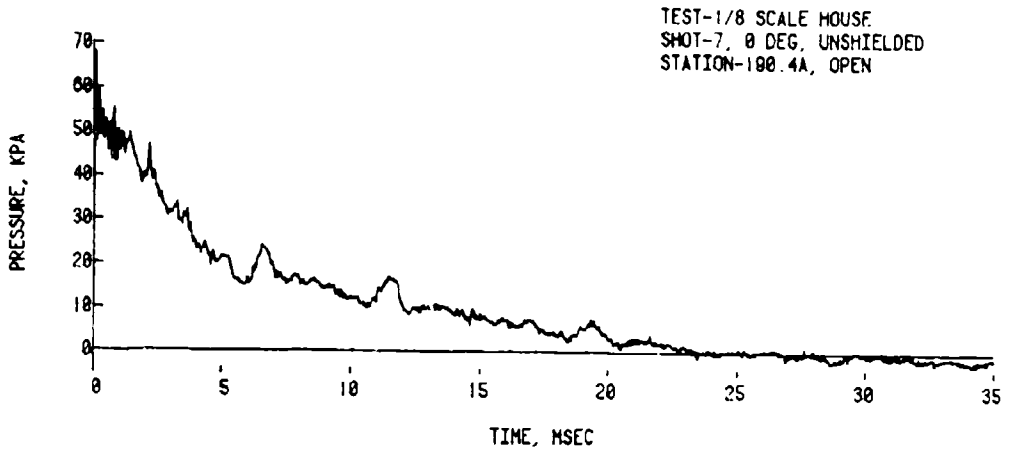


Figure [illegible] Records from open-ended [illegible] Stations 198.12C and 198.13C, Shot 6

APPENDIX F

Pressure-Time Histories, Shot 7





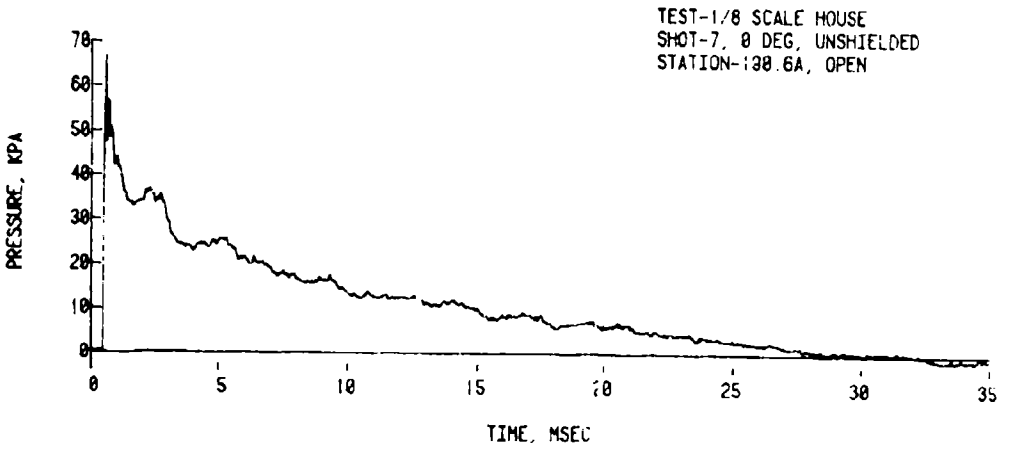


Figure E-1. Records from unshielded open model houses, 0 degrees, Stations 190.0A, 190.4A, and 198.6A, Shot 7.

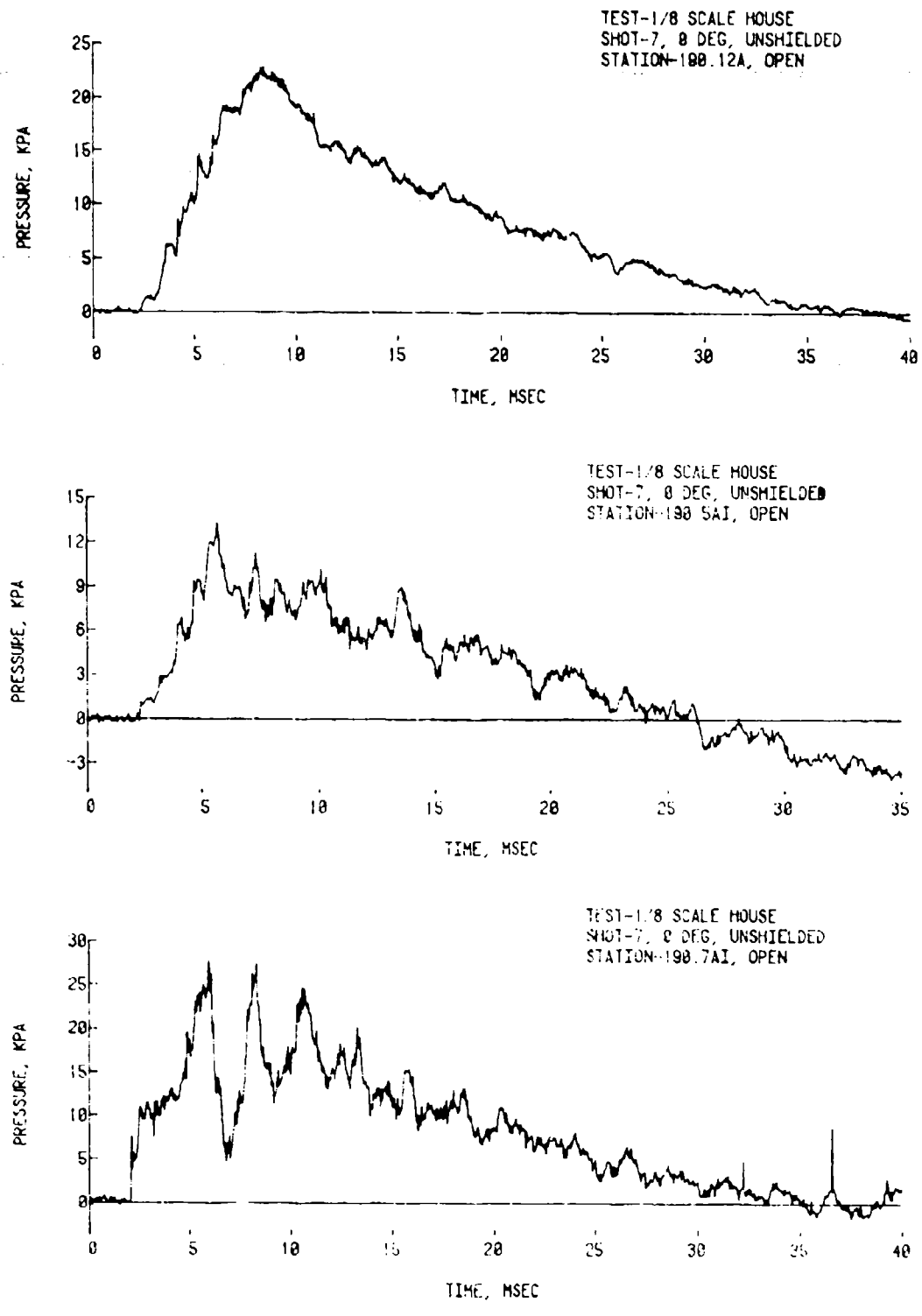


Figure I-2. Records from unshielded open model for 0 deg, Shot 7, Stations 190.12A, 190.5AI, and 190.7AI, Sheet

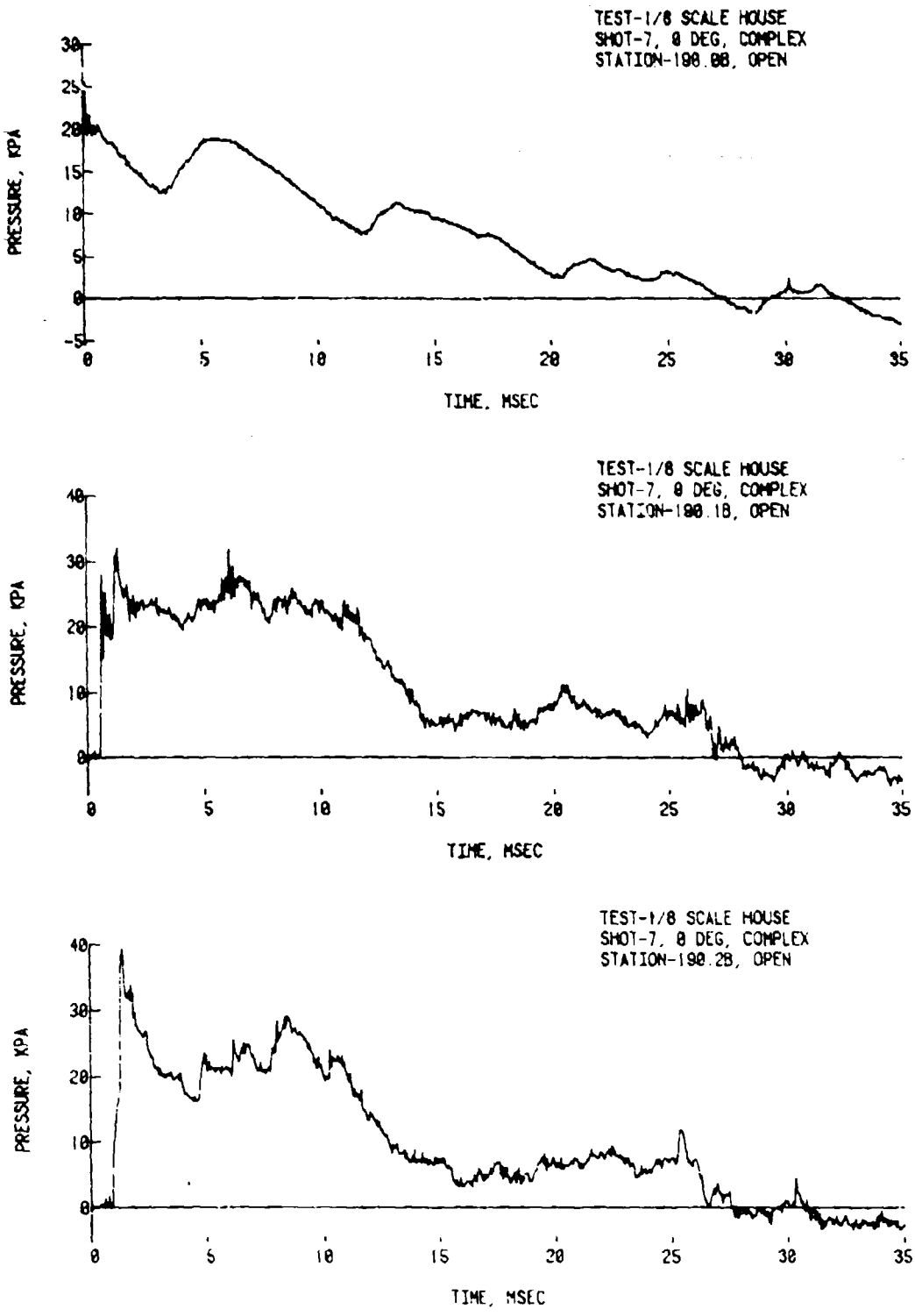
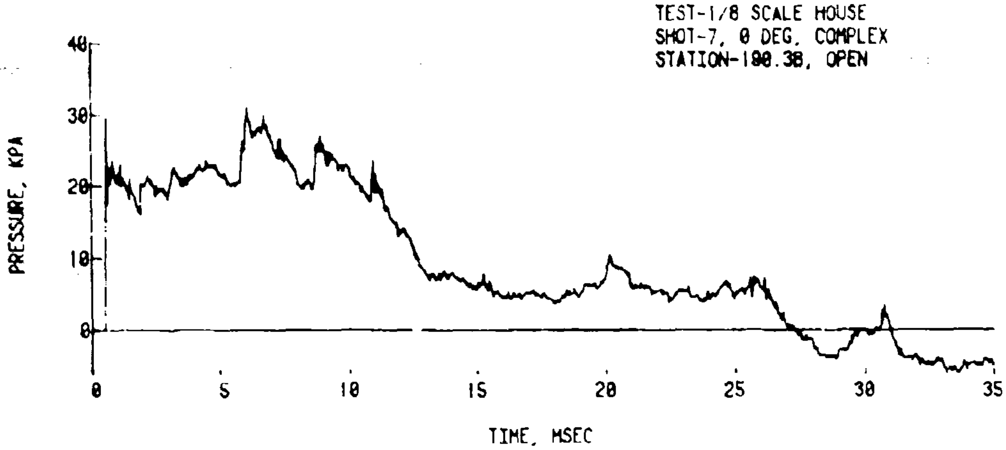
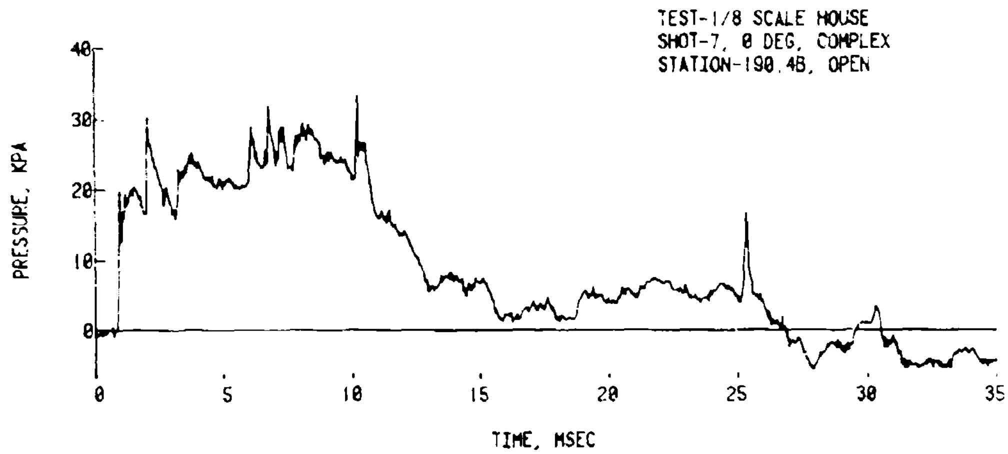


Figure 4-5. Records from open model house in complex, 0 degrees, Stations 190.08, 190.18, and 190.28, Shot 7.





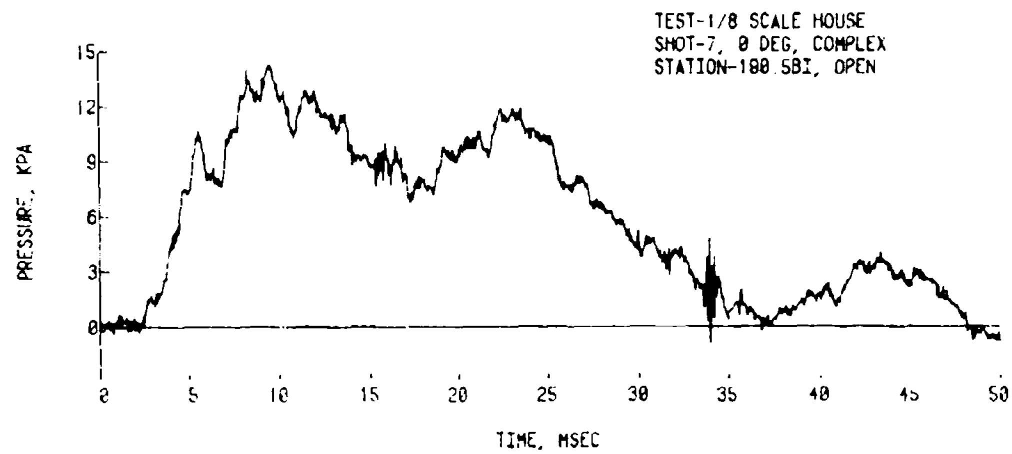


Figure [illegible]. Records from open model house in complex, 0 degrees, Stations 190.3B, 190.4B, and 190.5BI, Shot 7.

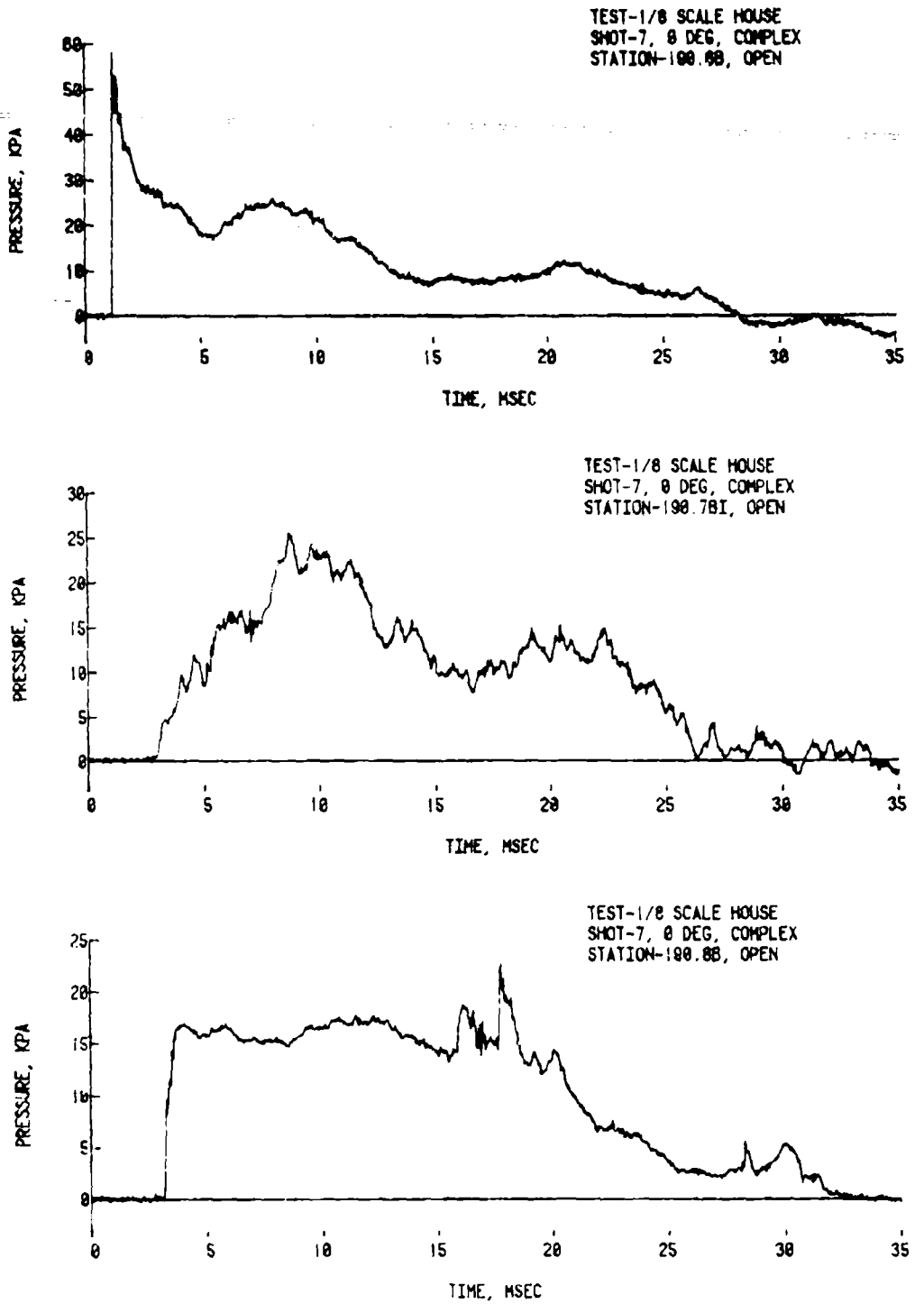


Figure I-5. Records from open model house in complex, 0 degrees, Stations 190.6B, 190.7BI, and 190.8B, Shot 7.

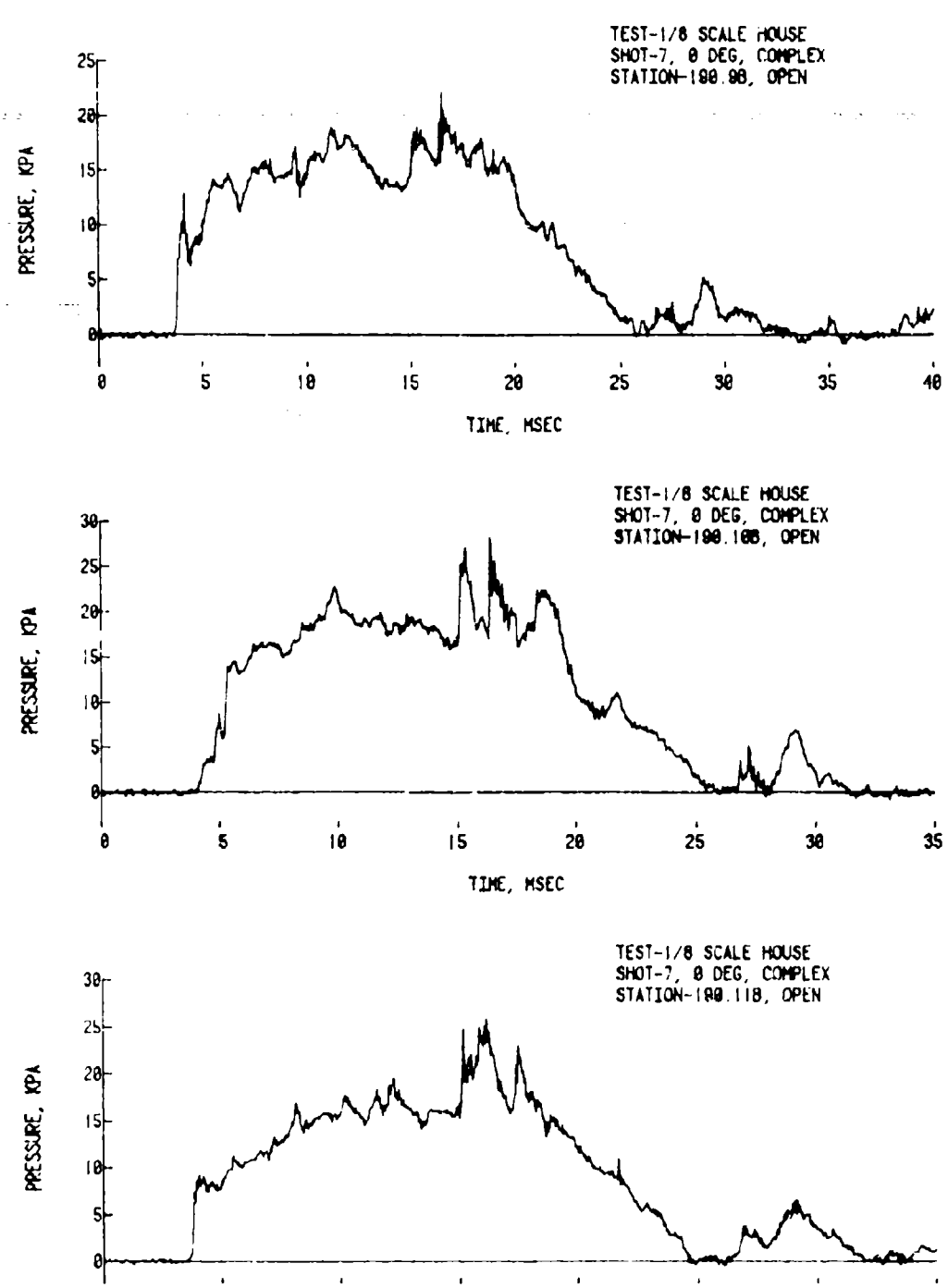


Figure I-6. Records from open model house in complex, 0 degrees, Stations 100.98, 100.108, and 100.118, Shot 7.

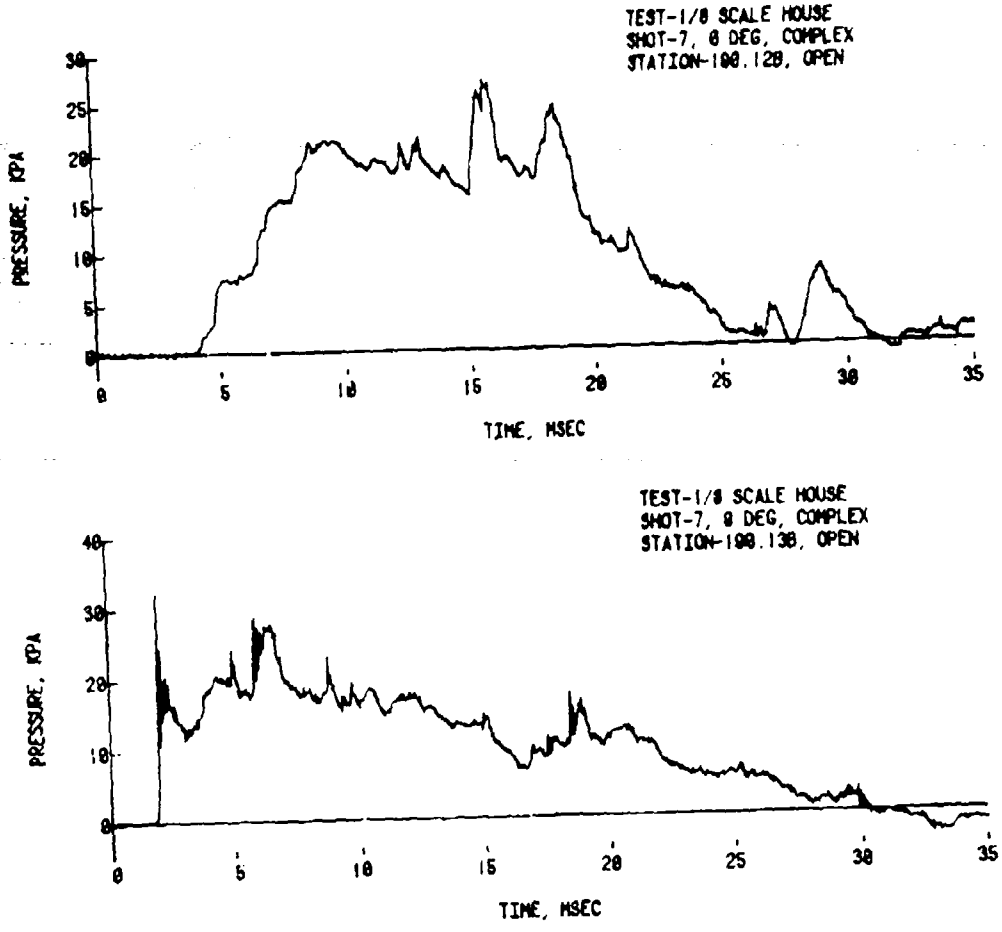


Figure F-7. Records from open model house in complex, 0 degrees, Stations 190.12B and 190.13B, Shot 7.

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